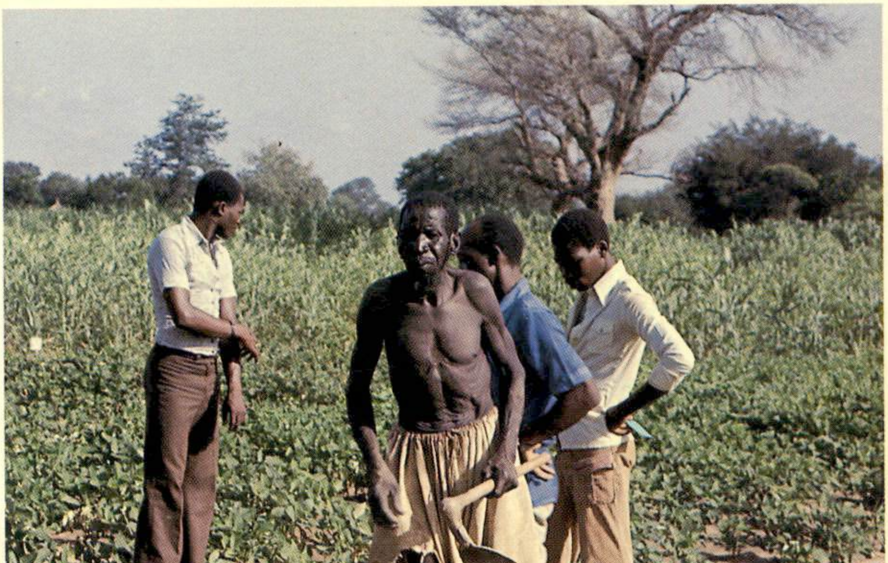
Food Grain Production in Semi-arid Africa



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Contents

Foreword

International concern about the food deficit problems of African countries has been amplified in recent times by the special difficulties which the hostile climate of countries in the semi-arid regions of Africa continue to impose on successful and increased food production. The situation calls for deliberate intensive research, development and educational efforts which will be aimed at overcoming the major constraints to adequate food production.

The international community, especially the Organisation of African Unity's Scientific, Technical and Research Commission (OAU/STRC), the United States Agency for International Development USAID, and the International Fund for Agricultural Development (IFAD), continue to support relevant research and development of food production systems which would be particularly cost-effective (productive) in the high risk environments of semi-arid Africa. While these efforts and support are commendable, there is considerable value in re-appraising national agricultural policies, research priorities and programme activities from time to time in order to effect timely and effective changes in the production systems.

The significance and advantages of this drought symposium which is organised under the aegis of SAFGRAD in May 1986 are that it has brought many national agricultural policy makers together and also distinguished international and national scientists to discuss certain key issues affecting food grain production in semi-arid Africa and to exchange views and experiences. The OAU/STRC which continues to serve as an appropriate platform for such dialogue and progress evaluation should be further encouraged. It is only within the context of such discussions, exchange of Scientific research experiences, and monitoring that meaningful progress can be made in African Agriculture.

It is very gratifying to note the successes in research and extension which have been achieved during the past decade and the progress which African countries in the semi-arid zones have made towards increased domestic food grain production. International and national support for this project continue to effect the desired impact for which the OAU expresses its appreciation.

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Preface

The food grains, namely Sorghum, Millet, Maize, Cowpea and Groundnuts are the staple food items of the people who live in the semi-arid regions of sub-Sarahan Africa. Production of these food grains in sufficient quantities to meet the increasing demands of the rapidly expanding rural and urban human populations there continues to face many constraints, including hostile and harsh climate, serious and continuous degradation of the fragile agricultural resource base and recurring droughts. These problems are further compounded by poor infrastructure, marketing systems, weak national research policies and programmes and extension services which receive relatively little support from national governments.

While local farming technologies are often sophisticated and contain valuable components for farming under high risk environments, these technologies also require important modifications to cope with the problem of sustained food grain production under an increasingly permanent farming system. The increased international awareness of Africa's food problems has given rise to increased research and development activities funded by a multitude of foreign donors and implementing agencies operating through national and bilateral agreements. Although these activities recognize the differences and similarities which exist between different national research programmes and priorities, there seems to be very little coordination of research and development activities within the region. SAFGRAD, Semi-Arid Food Grain Research And Development, Project funded by the USAID, IFAD, FAC and IDRC; and the Organization of African Unity Scientific, Technical and Research Commission, was established to coordinate agricultural research and development efforts for the major food grains on a regional basis in order to substantailly increase the quantity and quality of these food grains in 26 countries in sub-Saharan semi-arid Africa.

The activities of SAFGRAD over the past two years have exposed certain key issues which are crucial for effective food grain production in the region. It was therefore desirable to organize an international Drought symposium to discuss these issues.

During the first two days of the symposium, general papers reflecting the status, priorities and policy issues in food grain production were presented and discussed. In the next two days, scientists from diverse drought-prone African environment presented scientific papers and research reports in specialised sessions and working groups.

The working groups focused on pertinent problems currently constraining efforts to increase food production in drought-prone areas of semi-arid regions of sub-Sarahan Africa. Working sessions were organised along the main themes of the symposium which have been organised into the four parts of this book. In order to formulate recommendations and follow-up actions, subcommittees were organised comprising chairmen and rapporteurs for each working group. Based on the principal points raised in the papers presented and subsequent discussions, it was decided that the focus of the discussion sessions should be limited to common issues of highest priority to many countries. The following key areas were highlighted: policy issues, food security, food self-sufficiency and research priorities for drought-prone areas.

The discussions and recommendations of the working groups are included at the end of this book.

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Introduction

The causes of the African Food problem are diverse and yet interrelated, while the rapid decline of the resource base for agriculture in the semi-arid climatic zones of sub-Saharan Africa has significantly contributed to drought in many African countries, thus leading to the deepening food crises.

Furthermore, although biological, social, economic, and ill-defined agricultural policy issues also contribute to the food production crisis in Africa, drought-stress, poor soils and lack of efficient soil-water management techniques are the most severe constraints to food production in this region. There is abundant literature which discusses the inability of many countries in sub-Saharan Africa to grow sufficient food to feed their rapidly increasing human populations. However, the literature seriously lacks information on currently available technologies appropriate for the improvement and production of food grains under drought conditions in semi-arid sub-Saharan Africa.

In order to review these issues closely, SAFGRAD, Semi-Arid Food Grain Research and Development Programme, a Regional Research and Development Agency established to promote research and development of food grains, namely, Sorghum, Millet, Maize, Cowpea and Groundnuts in semi-arid sub-Saharan Africa, organised an international Drought Symposium at the Kenyatta Conference Centre in Nairobi, Kenya from 19-23 May, 1986.

The major objectives of this symposium were as follows:

- To review and document the current state of knowledge on food grain production, with special reference to semi-arid sub-Saharan Africa, and thus foster national agricultural research policy changes that will favour agricultural development in the region;
- to inventory current research activities on food grains, especially those whose major focus is to develop agronomic techniques which sustain good yields under drought stress;
- to synthesize technological data and policy information relevant to developing regional research strategies and programmes which counteract the short- and long-term effects of drought on food grain production;
- to promote the exchange of technical knowledge leading to the establishment of permanent and appropriate dryland farming practices in drought-prone areas; and
- to identify research gaps and needs on food grain production in semi-arid sub-Saharan Africa.

Specifically, the symposium addressed the following key issues which influence agricultural production in this region:

- Agricultural Policies

  The formulation of agricultural policies at national and regional levels which are conducive to relevant long-term agricultural research activities and to the conservation and improvement of the environment. No attempt was made to discuss specific national agricultural policies of SAFGRAD member states, rather a general treatment of agricultural policy issues yielded major policy-related constraints to food production in semi-arid Africa.

- Crop Production under Drought stress

  By the year 2000, most countries in Africa are expected to be faced with an enormous gap between internal food demand and food supply if drastic steps to accelerate food production are not taken. Increased agricultural production is expected to come from new development of arable land (26%), an increase in cropping intensity (14%) and higher yields (60%). If these goals are to be met, past trends in agricultural research and development must be changed to stimulate alternative paths to increased food production. In cooperation with national research programmes and international research centres, the improvement of good grains was given major emphasis during the last decade by regional programmes such as SAFGRAD. Repeated cycles of drought emphasize the need to develop short-cycle and efficient (in terms of moisture and nutrient utilization) crop varieties and alternative cropping systems incorporating such varieties in semi-arid regions of Africa. Discussion at the symposium focused attention on:
  - Major factors affecting plant establishment, such as planting systems, temperature, soil preparation and fertilization, pathogens and pests;
  - Intercropping practices, with major focus on making better use of limited moisture and soil nutrients; and
  - Adjustments in traditional food grain production systems under drought stress.

- Soil and Water Management

  Poor and declining fertility of the soil, accelerated by denudation of natural vegetative cover, increasing demographic pressures, drought stress, erratic climatic situations and erosion have been identified as major constraints to food production in the semi-arid regions of sub-Saharan Africa. Inadequate emphasis has however been placed on soil and water conservation and management techniques. The success of crop production under rainfed conditions depends not only on effective water harvesting (collection and storage) but also on the efficient use of water. A high rate of rainfall runoff makes it difficult for farmers to reconcile their planting dates with crop moisture requirements. It is therefore crucial to choose crop management systems that improve long-term water storage in the soil. Analysis of climatic patterns over the last two decades, and farmers' adjustments of their crop production techniques under drought stress conditions, were explored. Techniques already identified through research and traditional cultivation methods were also synthesized during this symposium.
- Farming Systems in semi-arid conditions.

  In most drought stress areas, the frequency and timing of rains have been more critical constraints to food production than the total amount of precipitation received. Integrated farming systems, including various components such as livestock, horticultural crops and agro-forestry not only minimize risks to the farmer but also provide continuous enrichment of the resources necessary for productive agriculture. This section focussed attention on the following issues:

- The combination of cropping and animal production systems to maximize the recycling of resources and economic use of available water, organic matter, fertilizer, labour and other farm resources.
- The use of crop residues as a fodder, animal traction for the intensification of crop production, and the improvement of soil fertility as components of farming systems.

The contributions in this book relate specifically to the themes of this drought symposium. The country papers which reviewed the state of agricultural research activities, programmes, policies and priorities in some SAFGRAD member countries are published separately in another book.

It is hoped that this collection would be useful as reference materials for formulating relevant agricultural research policies, developing and executing research programmes and establishing collaborative activities with relevant institutions and agencies operating similar programmes within the region.

ANTHONY YOUDEOWEI

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PART I

Agricultural Research Policies

1 Food Security Research Priorities in Sub-Saharan Africa*

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I. Introduction

Africa's recent agrarian history has been dominated by one overarching statistic – food production grew at roughly half the population growth rate from 1970 to 1984. But the bountiful harvests of the past two years provide a breathing spell to assess what has been learned about Africa's agrarian crisis and steps to meet it. A major issue is whether recent harvests are temporary or the beginning of an upward trend in the rate of growth of food production, a prequisite for closing the food-population gap.

Increasing food production is a central part of the food security challenge in Africa. But food security has two interrelated components: availability of food through production, storage and imports and (2) ability of all people in a nation to acquire a calorie-adequate diet. Since food production is only one dimension of the food security equation, it follows that increased food production cannot ensure regional, national or even household food security. In a nutshell, this explains why an essay on food security research priorities in Africa[1] must go beyond making a plea to step up food production research.

Part II defines and clarifies several basic concepts: food first, food self-sufficiency, food self-reliance, food strategy and food security. Part III lays out three long run problems that shape the food security research agenda: (1) the food production-population race, (2) the poverty, hunger and food insecurity battle, and (3) the employment problem. Part IV advances four caveats about research on food security. Part V, the core of the paper, lays out a food security research agenda for social and technical scientists.

Food security research requires the combined inputs from many disciplines such as economics, agricultural economics, nutrition, geography, crop science, animal science and food technology. But it also requires a major shift in the allocation of time of agricultural economists from micro to macro problems such as nutrition policy, food subsidies, grain storage and international trade. I conclude by noting that farming systems research in Africa is in decline and suggest that the reasons for this decline should be closely studied by food security researchers.

II. Clarification of Concepts

The core concepts in food policy/food security analysis are confusing and in need of clarification.

* The research supporting this paper was financed by the U.S. Agency for International Development, Bureau for Science and Technology, and Bureau for Africa under a "Food Security in Africa Cooperative Agreement", with the Department of Agricultural Economics, Michigan State University.

[1] Africa is used throughout the paper to include the 45 countries in Sub-Saharan Africa.

Food First

This populist expression was advanced by Francis Lappe and Joseph Collins in the early 1970s as an utopian appeal for all people on the planet to share resources and help the poor meet their basic needs, including food. In *Food First* (1977) Lappe and Collins, recommended a reorientation of national development strategies to give higher priority to food production, reduce the reliance on export crops and develop food distribution schemes to ensure that the poor have access to an adequate diet. Food first lost popular support in the late 1970s and the early 1980s as food production expanded in Asia and world grain prices fell. But the authors' concern over access to food is an enduring contribution.

Food Self-Sufficiency

This concept dominated the global food policy debates in India, China and other Asian countries in the 1970s; it is understandably popular in Africa today as a response to recurring drought and the great Ethiopian famine of 1985. Food self-sufficiency can be narrowly defined as the ability of a village, district, nation or a region to meet 100 percent of its staple food needs from domestic production and/or storage under all weather probabilities. A more popular definition of self-sufficiency is the ability of a nation to meet all of its staple food needs through local production and/or storage except during periods of extreme drought or natural disaster when commercial food imports and/or food aid are required. However, because the weather probability distribution is rarely defined by the author, it is hard to pin down what food self-sufficiency means in operational terms.

In the Sahelian region of West Africa, the concept of regional food self-sufficiency was endorsed by the heads of State following the 1968-74 drought. A Secretariat was established in Ouagadougou to mobilize donor support to enable the Sahel to achieve regional food self-sufficiency by the year 2000.[1] But regional self-sufficiency was never rigorously defined and it has become a moving target.

Food Self-Reliance

This concept emerged in the Third World in the 1970s to indicate a process of increasing domestic food production and reducing the reliance on food imports over time. Since the degree of food self-reliance is usually not specified, it remains a fuzzy concept in practice. But the concept has a powerful political appeal and it continues to be used in Africa.

Food Strategy

The concept of a national food strategy was endorsed by the Governing Council of the World Food Council in 1979 and followed by an aggressive campaign to encourage African states to prepare food strategies. The World Food Council recently boasted that 30 African countries have adopted or are seeking to implement national food strategies (Williams, 1985).

In 1980 the European Parliament held a special debate on world food issues. Following the debate, Commissioner Pisani advanced an "Action

[1] Intra-regional trade is implicit in the concept of regional food self-sufficiency. For a history of the Sahel recovery program see (De Lattre and Fell, 1984).

Plan to Combat World Hunger", also referred to as the Pisani Plan (Pisani, 1982). Pisani argued that project aid was not buying badly needed policy reform in Third World countries and that the concept of a food strategy could facilitate policy dialogue and lead to mutually beneficial policy reforms (Tollens, 1986). Since 1982, the Community has been active in supporting the implementation of food strategies (Strategic Alimentaire) in Zambia, Rwanda, Kenya and Mali (Lipton and Heald 1984; Davies and Lipton, 1985; and Commission, 1986).

The concept of a national food strategy is sound in theory. In practice I have observed that many of the strategies have been prepared by expatriates, most have relied on questionable secondary data and most have concentrated on food availability issues – (increasing food production and expanding grain storage). With the exception of Botswana's *National Food Strategy*,[1] most food strategies devote little attention to politics, policies and programs that shape access to food.

In sum, the World Food Council's aggressive promotion of national food strategies has been a hollow exercise – i.e. another passing fad.[2]

Food Security

In 1974 when the World Food Conference was convened in Rome, food security was the dominant theme even though it was never rigorously defined. But the concept of food security had little staying power following the Rome Conference because policy makers and donors gave priority to increasing food production and rebuilding world grain reserves. Food security came of age in the early 1980s. In an influential collection of essays edited by Alberto Valdes *Food Security for Developing Countries* (1981), food security was defined as "the ability of food deficit countries, or regions within countries, to meet target consumption levels on a year-to-year basis (Valdes and Siamwalla, 1981, p. 1), a definition that incorporates the effects of both supply and demand. In early 1986, the World Bank issued a food security policy paper *Poverty and Hunger* (1986) in which food security was defined as "access by all people at all times to enough food for an active, healthy life": Two essential elements are the availability of food and the ability to acquire it" (World Bank, 1986, p. 1).

In Southern Africa the concept of regional food security was embraced at the initial Summit meeting of the Southern Africa Development Coordination Conference (SADCC) held at Lusaka in April, 1980. At the meeting Zimbabwe accepted responsibility to develop a regional food security program for the nine SADCC states and subsequently designated its Ministry of Agriculture to act as the official agency in developing and coordinating SADCC's regional food security program. From 1982 to 1984 SADCC developed ten food security studies and projects that are being implemented by member states.[3] Following the prolonged drought in

[1] Botswana is implementing a food security program that is one of the best kept secrets in Africa. Now in the fourth year of drought, Botswana is providing supplementary food during some parts of the year to 60 percent of its total population of around one million. For an excellent synthesis of the evolution of food security planning in Botswana over the past decade see Holm and Morgan (1985).

[2] Since its inception a decade ago, the World Food Council has been unsure of its audience and overshadowed by the FAO, USDA, IFPRI and the World Bank.

[3] For a historical review of SADCC's Food Security Program, see Murphy (1982 and 1985), Muchena (1985) and Drane (1985).

natural resources and the availability of technology. Likewise, because of the extreme heterogeneity in agricultural conditions, political systems and ideologies, an essay on food security research priorities for Sub-Saharan Africa would be a vacuous exercise. The challenge is to develop food security research priorities for each of the five major regions (e.g., Southern Africa), taking into account the agro-ecological conditions, food security problems and ongoing research by regional organizations such as CILSS in the Sahel region and SADCC in Southern Africa. A concurrent step is for local scholars to develop national research priorities within a regional framework.

Food security research topics can be divided into five areas:

i Efficiency of agricultural production
ii Marketing
iii Food consumption and nutrition
iv Managing grain reserves, trade and food aid
v Food security policy options: national and regional.

Efficiency of Agricultural Production

Food security research will be sterile if it devotes exclusive emphasis to the study of the food system because cash crops, export crops and livestock can generate jobs and income to enable households to purchase food. Hence, the efficiency of agricultural production rather than food production research *per se* is the legitimate starting point for food security research.

Five research topics fall under the general heading of the efficiency of food and agricultural production:

a. Incorporating food security goals into the priorities of national agricultural research services
b. Food Production Policy
c. Industrial/Export Crop Policy
d. Irrigation Policy
e. Household Food Security

Food Security Goals

The managers of national agricultural research services are under pressure to justify their research priorities in light of Africa's food crisis and the multiple objectives inherent in development planning such as economic growth, food security, employment, foreign exchange, and income redistribution. Currently there is no established process of incorporating food security issues into the priorities of national agricultural research services. For a review of the problem of incorporating nutrition goals into national research planning see the collection of papers edited by Pinstrup-Anderson *et al* (1984). Longmire and Winkelman (1985) illustrate how domestic resource cost (DRC) analysis can be used to assess the comparative advantage of one commodity such as wheat in the national economy and, by implication, the relative emphasis that a national research service should devote to wheat. But, at present, economists have little to offer national research managers on the *ex ante* incorporation of food security goals into agricultural research planning for an entire country. Research is urgently needed on this topic.

Food Production Policy

Since the majority of the poor in Africa are engaged in subsistence food production, one of the most direct ways of increasing the real incomes of smallholders in food deficit countries in the short run is to increase the productivity of their main enterprise, staple food croops.[1] In food deficit countries, increasing the efficiency of producing staple food crops can increase the per capita availability of home-produced foods, raise cash incomes by selling some of the increased output or enable family food needs to be produced with less land and labor, thus freeing these resources for other income-earning activities such as cotton production or off-farm employment. Since off-farm employment can generate income and increase the demand for farm products, the farm/off-farm linkages should be given special attention.[2]

In food surplus producing countries such as Malawi, Zimbabwe, and the Cameroon, etc., the question of how much research emphasis to place on increasing food production is a complex issue that should be examined in a regional trade framework. Zimbabwe is a good illustration of the complexity of the problem because of its inherited dual agrarian structure, its post-independence policy of assisting small producers (communal farmers) increase their marketed surplus (especially maize and cotton) and because its maize policy is based on the premise that it has a long term dynamic comparative advantage in producing and exporting maize. Zimbabwe currently has approximately 800,000 smallholders and 4200 commercial farms. Presently Zimbabwe has a backlog of white maize genetic material for both commercial farmers and smallholders.[3]

But improving the efficiency of food production is a more complex task than developing improved technology – the main concern of technical scientists and farming systems researchers. Investments in marketing, processing and transportation are also required. These issues can be examined in a food systems framework (Riley and Staatz, 1981). Subsistence farmers are understandably reluctant to try to increase their income through specialization in one or two food and/or export crops if there is not a reliable market to purchase some of their food needs. In the long run, efficient input and output markets are the key in developing the intersectoral linkages that characterize economic development, which by generating increased incomes reduces poverty and food insecurity.

Industrial/Export Crop Policy

The third research topic for food security researchers is the selective study of key industrial crops such as cotton, and export crops such as tea in Kenya, coffee in Rwanda and groundnuts in Senegal. An illustration from Rwanda helps explain why research on an export crop such as coffee may be

[1] This section draws on Eicher and Staatz (1985).

[2] For a review of the literature on rural non-farm employment see Haggblade, Liedholm and Mead (1986).

[3] Maize yields in Zimbabwe are about 4.5 MT/ha on commercial farms and 1.5 tons on smallholders (communal farms) (Eicher, 1984) and Rohrbach (1985).

a higher food security research priority than research on the staple foods – beans and maize. Although coffee currently occupies only 3 percent of the arable land, it generates about 75 percent of Rwanda's export earnings. Smallholder coffee yields in Rwanda have declined 20 percent since independence in 1960 (Tollens, 1986). Coffee sold under the International Coffee Agreement (ICA) or outside ICA arrangements generates substantially higher returns per hectare than food crops such as beans. Moreover, smallholder coffee generates 550 man days of work per hectare per year, a crucial factor in a country with the highest population density in Africa and a need to expand rural employment opportunities. If smallholder income from coffee production can be increased they will likely purchase additional food from the market and increase family food security. In sum, food security researchers should be praised rather than criticized for pursuing some research on cotton, coffee, tea etc.

Irrigation Policy

Currently less than 5 percent of the arable land in Africa is under irrigation compared with around 30 percent in India. But in the wake of the drought in many parts of Africa, irrigation has emerged as a high priority investment that is being justified for its contribution to increasing the security of food production, rural employment generation and foreign exchange earnings.

Africa's irrigation history is marked with false expectations, cost overruns and a legion of failures (Eicher and Baker, 1982; and FAO, 1985). Following the devastating drought in the Sahel, grandiose plans were advanced to "drought proof" the Sahel by the end of this century. But the same problems that plagued colonial administrators, are emerging as significant barriers to irrigation in the Sahel. For example, the number of hectares of new land being brought under irrigation each year in the Sahel – around 5,000 – is about equal to the number abandoned because of unforeseen technical problems, and difficulties in developing farmer irrigation associations to maintain the ditches and canals and manage the schemes (Eicher, 1986). Nevertheless, new irrigation projects are under construction in many countries with the objective of increasing food production and food security. For example, Senegal is completing two dams on the Senegal river costing around a billion dollars with a capacity to irrigate 300,000 to 400,000 hectares. Botswana, now in the fourth year of a drought, is carrying out feasibility studies of several major irrigation programs that are explicitly designed to increase the level of food self-sufficiency (Botswana, 1985). In Zimbabwe, some 80 smallholder irrigation schemes atrophied during the civil disturbances of the 1965-79 period. Many of these schemes are being reopened but almost all are subsidized (Rukuni, 1984). Over the past four years in Southern Africa, I have noted a surge of interest among policy makers in irrigation coupled with a startling lack of information about the disappointing experience with irrigation in Nigeria,[1] Mali (Kamuanga, 1985) and the Bara project in Kenya where the cost is running about US$35,000 per smallholder. In summary, irrigated crop production will increase slowly in Africa over the next 25 to 50 years. Research should be an integral part of this evolutionary pathway. In my

[1] Nigeria has invested several billion dollars in River Basin Authorities and large scale irrigation projects in northern Nigeria. But most of these initiatives have turned out to be costly mistakes (Ogunbile, 1985).

opinion, research on irrigation is a medium priority topic in the food security research agenda.

Household Food Security

The study of household food security has historically been approached from at least four different and largely independent research traditions. First, anthropologists such as Fleuret (1979), Colson (1984) and others have invested substantial intellectual capital in gaining an understanding of food security strategies of households and villages. Second, geographers (Hunter, 1967 and Watts, 1984) and more recently economists have become interested in seasonal hunger and household food insecurity.[1] Third, the study of resource management and agro-forestry is being revived by donors some two decades after the pioneering research of Charreau and Vidal (1965). For example, the World Bank is encouraging research on agro-forestry and resource management (World Bank, 1985). ICRISAT/Hyderabad in India has recently merged its FSR and Economics units into a new Resource Management Department. The ICRISAT/Sahelian Center in Niger recently reorganized its research program into three departments: Sorghum, Millet and Resource Management. Fourth, over the past decade, farming systems teams have contributed to an improved understanding of how farmers incorporate risk into their farm – and to a lesser extent – their household decisions (Moock, 1986 and Rukuni, 1986).

The above research base should be carefully examined before pushing ahead with new research on household food security in resource poor regions.[1] I predict a repetition of past experience – social scientists producing volume after volume of reconnaissance and baseline reports in splendid isolation from technical scientists who are carrying out on-station trials in more favourable soil and rainfall conditions. In sum, caution is needed in designing a research program on household food security in resource poor regions. Ideally, household food security studies should be pursued by multi-disciplinary teams with financial support covering an initial period of a decade.[2] Two social scientists – Robert Chambers and Janice Jiggins are calling for "a revolution in agricultural research for resource-poor farmers" (1985). Let us recall that FSR proponents made the same appeal about a decade ago.

Marketing

Marketing research flourished in the 1950s and 1960s because of the proliferation of state marketing boards.[3] But research on marketing was dormant in the 1970s because agricultural economists concentrated on integrated rural development in the first half of the decade and FSR starting with Collinson's work in Kenya in 1976. Since 1980 marketing research has been growing in popularity for several reasons:

[1] David Sahn, IFPRI, is editing a collection of papers on Seasonal Household Food Security.

[2] Most scientists admit that it takes a decade, on the average, to develop and farmer-test a new plant variety for release to extension workers. Why shouldn't social scientists adopt a similar time frame when laying out research programs on household food security in resource poor regions?

[3] For a summary of marketing research in the 1950s and 1960s see Eicher and Baker (1982).

i. There is pervasive empirical evidence that many state marketing boards have turned against the interests of farmers.[1]

ii. In some African countries farmers are receiving a smaller share of the consumer price of basic grains relative to Asia (Ahmed and Rustagi, 1985).

iii. The emergence of grain surpluses in southern Africa in 1985 and 1986. In April, 1986, the FAO estimates that seven African countries had 2.7 million tons of exportable surplus of grain.

iv. The decision of some donors – especially the World Bank – to reduce project assistance and increase the allocation of assistance to Structural Adjustment Loans (SALs) (Reutlinger, 1986). The restructuring of government grain boards has been included in some of the SALs. Hence, research on how to restructure grain marketing systems is being encouraged by the Bank.

The marketing priorities for food security researchers over the coming decade include the following: (1) conceptual (2) market liberalization and (3) empirical studies. At the conceptual level neither the paradigm of political scientists Robert Bates (1981) nor the neoclassical economics paradigm can answer Elliot Berg's question: why don't LDC governments liberalize agricultural markets? (Berg, 1985a). Research on market liberalization is a high priority topic (Abbott, 1986). Presently, there is virtually no research base on the difficult art of helping to manage the transition from state grain boards to cooperatives and private marketing firms in Senegal, Mali, Zambia and other states.[2] For example, in early 1986 the Government of Zambia announced that the monopoly of Namboard (the state grain and marketing board) would be terminated. Under the new system cooperative societies and private firms will be able to compete with Namboard in buying and selling maize and fertilizer while allowing Namboard to remain the buyer of last resort and maintain the national buffer stock of maize (Zambia, 1986a). But the Government of Zambia does not have a transition plan to move from state to cooperative and/or private marketing. Moreover, most private millers have storage capacity for only two to four days supply of grain because they have ready access to Namboard silos and Namboard bears the cost and risks of maintaining the national grain reserve. Several millers in Lusaka recently posed the question: because of the uncertainty of government policy why should we lease or buy grain storage from Namboard or construct private grain silos? Why should we take on added risk during the transition phase?

Another important research topic is collecting descriptive information on marketing margins for the major staple food crops. Similar footslogging research has been done by farm management researchers for four decades in Africa.[3] But marketing debates on food crops are largely based on heresay evidence and artificial comparisons. For example, critics of government grain boards usually fail to bring evidence from alternative marketing institutions (e.g., private marketing) because government policy has restricted the role of private marketing agencies for decades. So its back to

[1] Arhin *et al* (1985); Bates (1981); Berg (1985 and 1985a); and Schmidt (1979).

[2] Studies of market liberalization are underway in Senegal by ISRA (see Morris, 1985) and in Mali by the Institute of Rural Economy, Food Security Technical Secretarial and Michigan State University. See Child, Muir and Blackie (1985) for suggestions on organizing research on alternative maize marketing systems.

[3] See the pioneering studies in the 1960s by Mike Collinson, David Pudsey, John Cleave etc cited in Eicher and Baker (1982).

the basics for marketing research. Marketing studies needed include studies of food systems (Riley and Staatz, 1981); grain boards (Dodge, 1977), (Schmidt, 1979), Muir (1984), Child, Muir and Blackie (1985), Blackie (forthcoming) and (Berg, 1985); parallel markets (Morris, 1985); fertilizer marketing and distribution studies (Crawford *et al*, 1985); and studies of household production, consumption, storage and marketing decisions (see Stanning, 1985 and Singh, Squire and Strauss, 1986).

Food Consumption and Nutrition

Half of the food security equation is concerned with the ability of people to acquire food. Urban consumption surveys were a popular research topic in the 1960s, but the field has been dormant for two decades with the exception of a few countries such as Sierra Leone[1] and Rwanda.[2] Consumption research is high on the priority list because it can answer two basic questions. First, have the changes in consumption in recent years (for example, from millet, sorghum and tubers to wheat and rice in West Africa and from sorghum and millet to white maize in Eastern and Southern Africa) been a response to a change in tastes or to relative prices? If the latter, they are reversible and subject to change through price policy. If the former, then it may prove difficult to "turn back the clock" to sorghum, millet, cassava, yam etc. Second, how do consumption patterns vary by income group? The answer to this question would enable the analyst to move beyond information on "average diets" to knowledge about diets of the malnourished. This information will be of strategic value in designing food intervention programs to reach targeted groups. Since there is a dearth of studies on consumption and nutrition, it follows that this type of research should be given increased priority by researchers in Africa.

Research on nutritional aspects of food security is in its infancy in Africa relative to research on food availability (production and storage) issues. Economists interested in nutrition have had great difficulty in making inroads into nutrition policy debates and even in lending agencies because nutrition policy is usually dominated by nutritionists and medical personnel.[3]

Managing Grain Reserves, International Trade and Food Aid

Since food security involves not only increasing the available supply of food but also ensuring that the poor have access to that supply, there is a need to develop an appropriate mix of domestic production, trade, price, marketing and other policies to supply food in a cost effective manner while increasing the real incomes of the poor. Developing such a policy mix requires a detailed understanding of how international trade and food aid (Reutlinger, 1984) can be used to help achieve food security goals. The use of trade and grain reserves to stabilize domestic grain supplies has been a major focus of work by the U.S. Department of Agriculture, FAO, IFPRI, and the World

[1] The results of an integrated national study of farm production, marketing, migration, rural small scale industry, consumption and nutrition in Sierra Leone are reported in Buérlée, et al (1982), and in Singh, Squire and Strauss (1986).

[2] The Agricultural Survey and Statistical Services (SESA) of the Ministry of Agriculture in Kigali is analyzing the results of a nation-wide consumption survey. For more information contact Serge Rwamasirabo, SESA, Ministry of Agriculture, Kigali.

[3] For a discussion of research priorities on consumption and nutrition see Pinstrup–Andersen (1983), Pinstrup-Andersen *et al* (1984); ISRA/IFPRI (1985) Reutlinger (1984 and 1986) and Singh *et al* (1986).

Bank (1986).[1] Research on grain reserves has examined (1) appropriate design of storage facilities, (2) the management of stocks, (3) the relative efficacy of food reserves versus insurance approaches such as the IMF's compensatory facility to ensure stable food supplies, and (4) the role of commercial imports and food aid in achieving food security goals. This research has demonstrated the high cost of stabilizing grain supplies solely through a system of grain reserves compared with grain reserves and trade. (Huddleston, 1984).

Research on agricultural trade has attracted only a handful of African agricultural economists over the past twenty-five years. This is a puzzle in light of Africa's heavy dependence on primary products (Wheeler, 1984). Despite the success of some export oriented economies such as Taiwan, South Korea, Hong Kong, and Brazil over the past two decades,[2] there is considerable skepticism in Africa in relying on food imports and export-oriented agricultural development strategies. There are valid reasons for such reluctance because of the awareness that food insecurity can originate in both international price movements and in fluctuations in the domestic yields of staple food crops. For example, wheat prices in international markets rose from $US 60 to $220 per ton in just 18 months in the early 1970s. More recently, the dramatic fall in the world price of cotton, Mali's main export, has imposed a severe fiscal crisis on the Malian economy. The cotton parastatal announced a 1985 producer price based on 1984 world market conditions but it turned out to be well above the 1985 world price.[3]. On the other hand, trade can bring some unexpected positive benefits. For example, the current coffee boom and the abrupt decline in oil prices over the past year, have contributed to the improved economic outlook in Kenya, and other coffee producing nations. Trade policy research should focus on cereal grains with emphasis on identifying the policy blocks – price and non-price barriers – to expanded grain trade within sub-regions such as West Africa and Southern Africa. A study of the economics of the proposed SADCC regional grain reserve is being carried out by Fidelis Mangwiro and Mudziviri Nziramasanga under the University of Zimbabwe/Michigan State University Food Security Research Program.

Food Security Policy Options: National and Regional

The "priorities of priorities" in my proposed agenda is research on policy options at the national and regional levels in order to generate information on the cost and trade offs in achieving food security objectives. Because of intra-regional trade linkages, it follows that the national and regional research programs should be developed as a unified package and undertaken through a regional research network. Because African economies are integrated into the world economy through trade linkages, a logical question is whether the computable general equilibrium models (CGE) used by researchers in Egypt, India and South Korea have a role to play in Africa? DeJanvry reports that:

> The trade-offs implied between growth of different sectors, security of

1 For a brief summary of the state of the art on grain reserves see the World Bank, (1986).
2 For an excellent summary of trade policies of various countries since 1960, see Krueger (1984).
3 The world price of cotton in domestic currency terms in Mali fell by 50 percent between 1984 and 1985.

> food entitlements for different social groups, and short-run versus long-run effects are far from obvious and were partially captured in the results we presented from multi-sector, multiclass economic models for India and Egypt. In this new context, Third World countries must, consequently, design their agricultural policies and their strategies of security of food entitlements with a clear understanding and an explicit quantification of these trade-offs (De Janvry, 1986, p. 37).

But the number of trained analysts in African countries is small relative to the number available in countries such as India and Egypt to carry out general equilibrium studies. Moreover, the data base is extremely inadequate for CGE modeling in Africa.

Researchers in Africa should concentrate on partial equilibrium and sub-sector studies with initial emphasis on the one or two most important staple foods in the national economy. For example, because maize accounts for roughly half of the calories consumed by the average Zimbabwean, the University of Zimbabwe – Michigan State University UZ/MSU) food security research team is carrying out a comprehensive study of the maize sub-sector. Steve Buccola and Crispen Sukume have developed an econometric supply and demand model for the maize industry to assess *ex ante* the aggregate impact of pursuing alternative grain pricing, storage and trade decisions (Buccola, 1985). Godswill Makombe is carrying out a pilot study of the groundnut subsector in Zimbabwe with initial emphasis on the technological package available to communal farmers (smallholders). The UZ/MSU team in cooperation with Jim Longmire of CIMMYT is using the subsector framework to examine policy options facing the wheat industry in Southern Africa. After a year of experience with subsector studies the UZ/MSU research team concurs with Shaffer's observation that "the subsector represents a meaningful and manageable division of the economy for comprehensive investigation" (Shaffer, 1970). The UZ/MSU team will synthesize its experience with three subsector studies and develop methodological models for researchers in the SADCC region. But much conceptual work remains to be done on developing approaches to the study of food security policy options in national and regional economies.[1]

VI SYNTHESIS

It is time to stop treating each of the 45 countries in sub-Saharan Africa as if they were the same. Because of seven colonial histories, 1000 ethnic groups and extra-ordinary heterogeneity in agricultural conditions and stages of development, it would not be fruitful to prepare broad food security research priorities for sub-Saharan Africa. Instead, I recommend the development of food security research priorities on a national basis within a regional framework (e.g., Sahel, Eastern Africa, Southern Africa etc).

Food security research is in its infancy. It is at a comparable point to where Farming Systems Research (FSR) was a decade ago. Food security and FSR are both multi-disciplinary enterprises. Food security researches should devote substantial attention to some of the theoretical and

[1] Studies on national food security policy options include the following: Aboyade (1985); Byerlee (1985); (1985a); Berg (1985a); Buccola (1985); Ellis (1982) and Ellis *et al* (1985); Jabara (1985); De Janvry (1986); D'Silva (1985); Timmer (1984); Eicher and Staatz (1985); Pervis and Nyondo (1985) and Gerrard and Roe, (1983).

conceptual issues before plunging into empirical studies across Africa.

FSR is now in decline in Africa. The reasons for the decline of FSR should be carefully studied by food security researchers. FSR is in decline because it has been oversold, it has often been divisive,[1] it has been overfunded relative to the state of art of the field, it is often carried out by expatriate-dominated teams independently of national agricultural research services,[2] and there are some difficult statistical problems in comparing on-farm with on-station trials. Finally, I have observed that FSR has often been carried out in splendid isolation from the national food and agricultural policy debates.[3]

The decline of FSR in Africa is healthy in my judgment because there is a need for FSR to step to the rear and become a handmaiden to commodity research teams – not an equal partner with separate FSR departments. The challenge is to retain the core of FSR (on-farm research) as an integral part of national agricultural services. On-farm and on-station research are complementary activities and should be conceptualized, financed and implemented by national research services.

Food security researchers can gain valuable insights from the rise and decline of FSR. First, is the need to clarify the definition of food security and the objectives of food security research. Second, is the need to restrict research to a limited range of topics so that food security research does not become synonymous with agricultural development. Third, is to avoid financing independent teams that have little probability of being financed and sustained after donor funding is exhausted. Fourth, just as FSR generally lacks a strong macro policy orientation, it is important for food security research to have a strong micro foundation. Studies of the efficiency of agricultural production are the legitimate starting in food security research.

In sum, food security research is a legitimate and growing research area that encompasses two main elements – food availability (food production, storage and trade) and the ability of people to acquire food through home production, the market or food relief. The challenge now is to enlist the cooperation of scholars in a wide range of disciplines to carry out studies over the next decade. The institutionalization of food security research in African institutions should be dealt with today rather than five to ten years down the road.

Since agricultural economists have played an important role in justifying research on food security,[4] what are the implications of this essay for the discipline of agricultural economics in Africa? Agricultural economics research is at a profound turning point from micro to macro. The surge of interest in food security research is a manifestation of the growing maturity of the discipline. The question now is; what is the proper balance between micro and macroeconomic research? The present 80-20 micro/macro ratio is unsatisfactory in my judgment. A ratio of around 50-50 is desirable and it can probably be achieved by the mid-nineties.

[1] For example, see the note "FSR Gains a Foothold in the Gambia" (Russo and Patrick, 1984).
[2] Some donors are now wisely incorporating FSR into comprehensive projects to strengthen national agricultural research services.
[3] Senegal is a rare exception because there is a small macroeconomic research group (BAME) in the national agricultural research service.
[4] See Reutlinger and Selowsky (1976); Reutlinger (1984 and 1986); Sen (1981) and Valdes (1976).

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2 SAFGRAD's Approach to Enhancing the Generation of Suitable Technologies for Increasing Food Production in Drought Stressed Areas

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Introduction

Crop productivity in semi-arid regions of Africa is generally characterized by low yields which can be attributed to low technology input, harsh environmental factors, poor policy structures and lack of political commitment to allocate more resources to agricultural development. While a more congenial policy is necessary to bring about improvements in agricultural production, little can be achieved in the absence of improved technologies appropriate to conditions prevailing in each country and adapted to its social, economic and environmental conditions. Despite concerted efforts of NARS, IARC's and regional support programmes major break-through in food grain production in semi-arid regions of tropical Africa is yet to be attained. Food grain research needs to focus attention on making available varieties that are high yielding, resistant to drought, disease and pests. Crop varieties also need to be responsive to low-medium levels of inputs and management.

The drought that destabilized food grain production in many countries of Africa is not unique to the region. Although the drought of the 1960s, 1970s, and 1980s of the Sahel and in Ethiopia received world-wide attention, it was reported that more than 20 droughts have occured since the 16th century in the same region. Previous patterns of climate seem to suggest that drought occurs in one or more regions of Africa every year. Two or more droughts affect large areas of the continent every decade while extemely protracted and widespread droughts occur about three times in a century; although the precise geographical areas of incidence is not predictable (FAO, 1983, 1985). In general, the erratic pattern of rainfall distribution, lack of appropriate water harvesting techniques as well as poor soil management techniques to conserve moisture, have also contributed to poor food grain production.

As reported elsewhere, food production in the semi-arid regions of sub-Saharan Africa has not kept pace with population growth (Eicher 1985, 1986, UN 1979). Increased consumer demands shifted the position of many African countries from food exporters to importers diverting resources from urgently needed national development programmes.

The purpose of a regional research cooperation is to enhance the flow of potentially relevant food grain production technologies among research and development institutions (NARS) in order to speed up the process of technological change necessary to bring about self-sufficiency in food production. Technologies that could alleviate some of the major constraints (drought stress, biotic constraints, such pests diseases including striga, and socio-economic factors etc) and minimize risks to the farmer, need to be developed.

The first part of this paper outlines collaborative research activities to sustain the generation of innovations among participating national research programmes (NARS). Following this, strategies for facilitating the exchange of technical information among scientists and extension workers are discussed. Finally, this paper points out some important considerations for facilitating regional research networking activities.

SAFGRAD Activities

The thrust of the Food Grain research programme activities are:

- to promote the improvement of food grains i.e. sorghum, maize, millet and cowpea by supporting regionally oriented research in order to increase food grains production in semi-arid regions of sub-Saharan Africa;
- to coordinate research activities in order to minimize the duplication of efforts and also to mobilize resources so as to foster a dynamic inter-Africa Research Cooperation at regional and sub-regional levels;
- to facilitate the dissemination of germplasm and related technologies through support of systematic regional trials and networking activities;
- training (both short and long-term) to improve the national research capability of its member countries;
- to provide broader forum for continuous interaction and dialogue among scientists and policy makers of member countries in order to enhance regional research cooperation and also address agricultural policy issues.

Approach

Sustaining the generation of technology

The time required for the development of technological breakthroughs in unfavourable semi-arid regions of Africa should not be underestimated. The following pages summarize advances that have been made by SAFGRAD cooperators to date.

Semi-arid Food Grains

The SAFGRAD-IITA research has emphasized the improvement of maize and cowpea varieties and production techniques.

Maize

The major thrust of maize improvement has been the development of early to medium-maturing varieties. Two high-yielding varieties noted as SAFITA-2 and SAFITA-104 have been widely tested in national programmes; these have either been released or are in the pre-release testing stage in Burkina Faso, Ghana, Cameroon, Mali and Benin (IITA/SAFGRAD 1984, 1985).

SAFITA-102 is a medium-maturing, high yielding variety for the Northern Guinea Savanna zone that has been developed and widely tested in many SAFGRAD member states. In cooperation with CIMMYT, the SAFGRAD/IITA collaborative research programme has identified a high quality protein (Pool-34 QPM) and already included it in the regional testing programme (SAFGRAD/IITA 1986).

Agronomic constraints to maize production in the region were identified.

Major agronomic practices that minimize the risk of drought stress and increase maize yield are improved soil tillage, tied ridges, use of early varieties, and maize-cowpea rotation practices. Deficiencies of phosphorus and nitrogen are the soil fertility problems and moderate application of fertilizer was recommended (SAFGRAD/IITA 1985, 1986).

A methodology for identifying genetic characteristics of drought resistance has been developed and some progress made towards identifying varieties and populations comparatively tolerant to drought. Techniques for use of maize crop residue to improve yields under traditional systems have been developed. These techniques improve water infiltration and soil-water content and decrease termite activity.

Resistant varieties

A multiple disease resistant and high-yielding variety, KN-1, was released for moderate (700 mm) rainfall ecological zones. It has been successfully evaluated in many SAFGRAD member counties (SAFGRAD/IITA 1985, 1986).

SUVITA-2, a drought and *Striga* tolerant variety, was developed and widely tested and is included in the pre-extension trials in many countries. Another variety, 58-57 has also been shown to have a high level of resistance to *Striga* (SAFGRAD/IITA 1986).

Local cowpea varieties have been collected, evaluated and screened for extra early maturation under various farming systems in the semi-arid zone.

Considerable progress has been made in defining and recommending practices for maize-cowpea cropping systems in the Northern Guinea Savanna zone and some progress made for sorghum and millet/cowpea intercropping systems.

Progress has been made in identifying aphid bio-types and resistance mechanisms to these bio-types, identifying cowpea cultivars with strong antibiosis, and screening materials showing aphid resistance at the seedling stage.

Storage studies have demonstrated that bruchids are the most serious insect pests to cowpea storage in the zone and work is in progress to develop integrated pest management control methods.

Sorghum and millet

The Eastern Africa SAFGRAD/ICRISAT Sorghum and Millet Improvement Coordination Unit, based in Nairobi, was started in 1982. Ten countries, including North and South Yemen, are participating in the regional sorghum and millet research network activities.

Most of the elite materials of sorghum and millet were developed in the region from the national research programmes, and materials were also obtained from ICRISAT. During the last three years, the Eastern Africa Cooperative Regional Sorghum Trials produced the following elite materials

- 10 long-cycle improved lines of sorghum for the high elevation zone (above 1800 m);

- 9 improved sorghum lines for the intermediate elevation ecological zone (1500-1800 m);
- the low elevation (less than 1500 m) regional trials have identified 17 entries that are relatively high yielding;
- the regional trials in very dry lowlands, although adversely affected by repeated cycles of drought, have developed 11 short-cycle sorghum varieties.

The Eastern Africa Sorghum and Millet Improvement Coordination Unit has continued to enrich the national programmes with improved sorghum germplasm from diverse sources. Furthermore, the three annual workshops held thus far (in Ethiopia, Rwanda and Tanzania), plus on-going regionally oriented research, have stimulated and revitalized the disrupted research coordination activities of East Africa.

West Africa

The ICRISAT developed varieties E35-1 and Framida have been tested in SAFGRAD member countries.

The SAFGRAD/ICRISAT sorghum and millet improvement programme based at Samaru, Nigeria achieved the following results:

- about 1000 lines of sorghum of tropical origin were selected and critically evaluated for significance of insect and disease resistance, suitability for planting across a range of environments (stability), mold resistance, and yield;
- several promising varieties were identified for *Striga* resistance;
- 6 improved sorghum varieties of Nigerian origin were evaluated in several SAFGRAD member countries;
- several millet and sorghum lines were evaluated for stemborer and shootfly resistance.

Soil water Management Research

Soil-water management research was based at Kamboinse Agricultural Experiment Station, Burkina Faso.

The main research findings of this programme can be summarized as follows (SAFGRAD, 1985):

- mulching with crop residues is extremely effective in increasing yield, especially under no-till conditions;
- tied-ridges reduce water and soil erosion losses by surface runoff and increase yield (zero-runoff concept). Tied ridges can be improved by placing mulch in the catchment basin;
- mulching and tied ridges reduce weeds and frequency of disease infestation;
- higher yields result from better surface water management, better varieties, more fertilizer and more actual hours of labour;
- animal traction as a source of draft can be used to build terraces, contour ridges, drainage ditches, and many other water conveyance and storage structures, for better soil water management.

Facilitating the Exchange of Technical Information

Information exchange is facilitated through the organization of workshops, conferences, seminars and training. The primary aim of training is to help build up "critical mass" of well trained researchers and technicians for research in member countries. The overall activities and SAFGRAD strategies for development and transfer of technologies are as depicted in fig. 1 which is a schematic representation reflecting the "input and output functions" in enhancing the generation of technology, sustaining continuous flow of technical research information, strengthening research activities of national programmes and speeding up the process of technology transfer. The operational scheme of SAFGRAD as indicated in fig. 1 consists of two major components. The first component (A) is enhancing the improvement of crop varieties and related food grain production technologies. Technology generation is facilitated through a regionally coordinated system of collaborative research conducted by scientists of national research programmes (research networking) and international research centers (i.e. IITA and ICRISAT). The second major component (B) is to facilitate testing and adopting of technologies through a system of national trials conducted at national research stations and on farmers fields.

The Accelerated Crop Production Production (ACPO) which has been operational in five countries (Mali, Senegal, Cameroon, Togo and Burkina Faso) served as vital links between national research and extension services, and farmers. The overall on-farm testing research that has been supported through SAFGRAD programme attempts to narrow the yield gaps attained at research stations and on farmers' field.

Collaborative Research Networks

Considerations

Research networking among member countries of SAFGRAD has gained momentum during the last five years. This regional research cooperation enables researchers and institutions not only to exchange improved research material and technical information but also to forge good working partnerships in order to minimize duplication of efforts, and accelerate the transfer of research results to farmers. Crop commodity oriented and related research networks are affected through the technical backstop and assistance of international agricultural research centres (IARCs) and through the coordinated efforts of regional and sub-regional African organizations (SAFGRAD, INSAH, SACCAR, etc.) which were established by the OAU or respective regional member states.

Research networking activities in sub-Saharan African is influenced by a series of research and coordination activities. The important elements for effective collaborative research and technology transfer networking activities are briefly discussed below.

Research Policy is an important initial consideration

Several research networks have become operational without the existence of conducive agricultural research policies both at regional and national levels. However, such policies could greatly enhance regional research cooperation. Responsive policies could improve the allocation of resources to agricultural

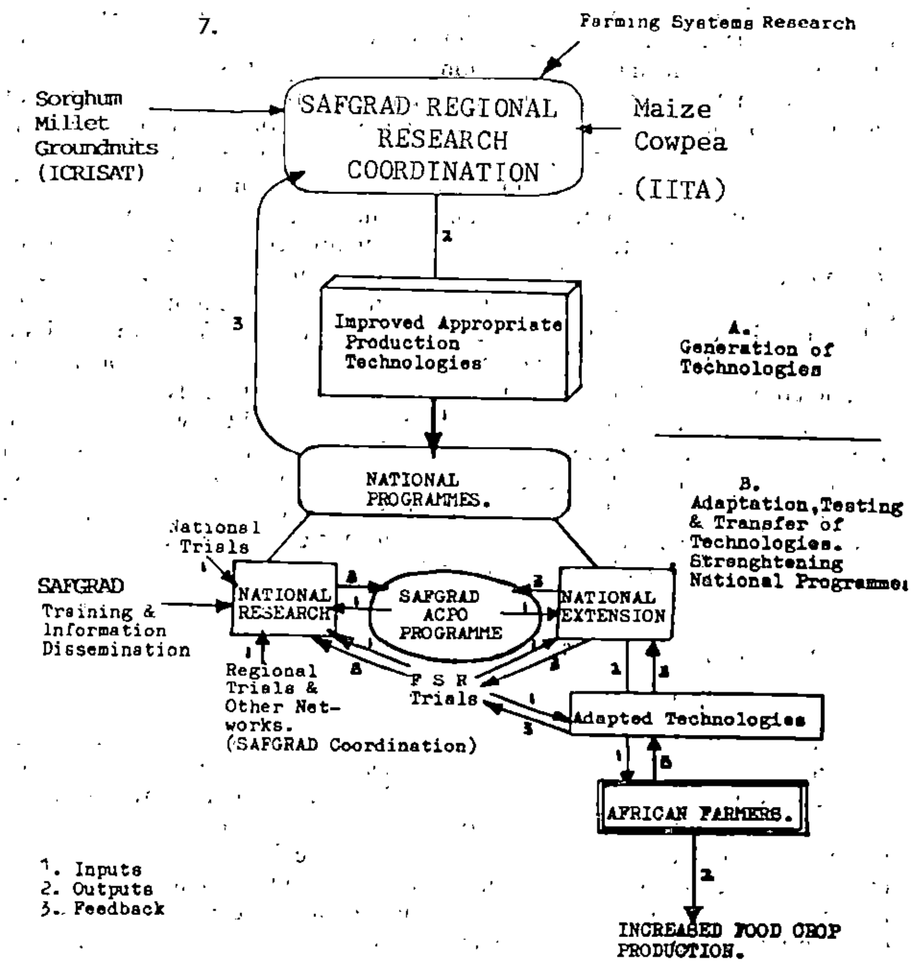


Figure 1. Flow chart of SAFGRAD Technical Input/Output functions to strengthen National programmes in member countries, leading to increased food production by African small scale Farmers. Source: Framework for the Long Term Planning of SAFGRAD by Stoop & Youdeowei (1985).

development in general and research in particular. Poor infra-structures, and under-utilization of qualified researchers are among the major constraints of National Agricultural Research Systems (NARS) which impede the full development of their research capacities and management. For example, less than 7% of financial resources of most African countries is reported to be allocated to agricultural development whereas 80% of the workforce depends primarily on agriculture (Spencer 1985).

The second important element is *Viable Collaborative Research.* As depicted in fig. 2, collaborative research with IARCs, NARS and other regional research agencies is necessary in order to ensure the generation of relevant technologies. For example, SAFGRAD collaborative regional research programme focuses on developing high yielding, short-cycle cultivars (of maize and cowpea with IITA and sorghum and millet with ICRISAT) that could also withstand environmental, disease and pest stresses.

The third consideration in realizing research networks is the *assessment of available regional germplasm and related technologies that complement on-going research of various national research programmes*. It is important that national scientists of participating countries play the major role both in assessing available technologies and identification of major constraints that impede the improvement and production of food grains. Through regional networking systems, inter-country research link is facilitated. This could lead to broader research cooperation and eventually to the development of stronger national programmes. Such programmes could then be able to assist weaker national programmes by providing elite germplasm to pursue applied research and verification trials. Such an activity would enhance regional collaborative effort among participating countries.

Another important consideration for regional research cooperation is *to identify priority areas of research sub-components of each major research commodity network*; for example, of sorghum, millet, maize, cowpea, etc. (fig. 2 cons. 4), that are of regional significance. It should be emphasized that the improvement of food grain, regional variety trials of elite materials, selection for drought, disease and pest tolerance, tillage practices to conserve moisture, etc, are also important elements of research networks. It is obvious that the choice of the type of research activity by each participating country would depend on the availability of adequately trained researchers, appropriate resources and magnitude of particular constraints to food grain production in that country.

The fifth important consideration is to *establish data base in each NARS in order to sub-group and intensify research cooperation at different levels of research interactions* (fig. 2 cons. 5). The success of research networks, therefore, depends on national research capability as well as dedicated participation of research scientists themselves.

Training and technology transfer are important considerations for successful research networking activities. Both short and long-term training is necessary to fill research gaps within the national research programmes. Unless the NARS are continuously enriched and staffed with adequately trained scientists, it is unlikely that research networking could benefit participating countries since the few scientists that may be available are over-burdened with too many responsibilities. Concurrently, functional linkage of NARS and the National Extension System (NES) is of paramount importance. On-farm testing both at the preliminary level and using appropriate farming systems research (FSR) methodologies could provide feedback to improve research priorities and strategies.

Existing Networks

In collaboration with various agencies, IARCs (IITA and ICRISAT) and NARS, SAFGRAD has facilitated the realization of the following research networks:

Maize and Cowpea

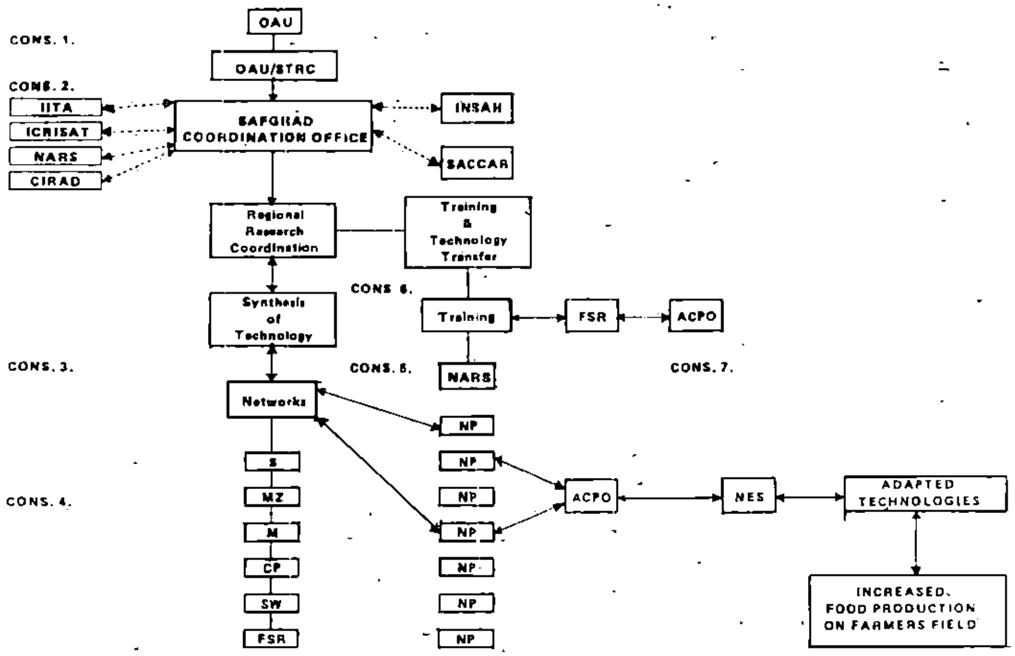
Regional cooperative networks were established since 1979. The SAFGRAD/IITA research network on maize and cowpea involves more than 23 member countries. In maize, the thrust of SAFGRAD/IITA research has been to enhance the development of short-cycle, disease and pest resistant cultivars, including improving agronomic practices in order to minimize risks to farmers. Similarly, the focus of the cowpea research and its network activities has been to develop early maturing cultivars resistant to drought stress and *Striga*. Breeding for insect resistance and integrated pest control are important components of the cowpea research network activities. Regional trials and evaluation of elite germplasm and improved agronomic practices, soil and water management techniques also constitute the research cooperative activities of maize and cowpea. Training of scientists and technicians has also been an important activity of SAFGRAD since the success of regional research cooperation depends on the level of training and experience of participating national scientists that could eventually direct the networking activities by themselves. The maize and cowpea network is further strengthened through the annual monitoring tour that involves a team of scientists from selected member countries and SAFGRAD/IITA scientists.

The Eastern Africa Sorghum/Millet Research Network

ICRISAT/SAFGRAD jointly initiated this programme in 1982. Ten countries including North and South Yemen are participating in the Eastern Africa regional cooperative research. The programme has succeeded in bringing together various national programmes through scientist to scientist interactions. The main focus of Eastern Africa regional research network has been the evaluation of elite materials made available from four ecological zones (high and intermediate elevations, low elevations and dry lands). Initially, elite germplasms were identified from participating countries, ICRISAT and other sources. Since 1984 the Eastern Africa Cooperative Sorghum Screening Nursery (EACSSN) was set in motion. The Coordinator of the network received entries from diverse sources and screened several lines before making selected lines and entries available to participating member countries in the region.

Regional workshops for discussing cooperative research trials have been held in different countries on a rotational basis. Four annual regional workshops were held in Ethiopia, Rwanda, Tanzania, and Uganda, respectively, since 1982. These rotational workshops have enabled the sorghum and millet researchers of the region to effectively share their experiences and further improve linkages among countries of SAFGRAD which facilitated the flow and exchange of technical information and germplasm. During the annual workshop, the main centre of attraction is usually the sorghum and millet research programme of the host country, covering research activities in breeding, agronomy, inter-cropping, plant

Figure 2. SAFGRAD collaborative research networks and transfer of technology.



Consideration 1. Conducive Agricultural Research Policy at national and regional levels
" 2. Viable collaborative research
" 3. Assessment of available technologies and organizing network activities
" 4. Identification of global research constraints and network sub-components
" 5. Compiling and establishing data base on each national research programme
" 6. Uninterrupted training, seminars and workshops

Consideration 7. Technology Transfer programmes linking NARS and NES to obtain feedback on adoption.

protection and utilization of these crops. One full day of the workshop is fully devoted to field visits of sorghum and millet research. Furthermore, the results of the regional cooperative trials are discussed after presentation of a summary report by the regional coordinator.

Sorghum Research Networks of West Africa

Sorghum improvement in West Africa has been strengthened since the last two decades. Regional cooperative research was initiated since the JP 26 Project of USAID and OAU/STRC that was based in Samaru, Nigeria at the Institute for Agricultural Research of Ahmadu Bello University. Since 1975 the ICRISAT West African Sorghum Improvement Programme has provided germplasm to participating national research programmes. SAFGRAD collaborates with ICRISAT and INSAH to strengthen the West African Sorghum Research Networks. In addition to evaluation of elite materials and identification of suitable varieties for Guinean, Sudano-savanna and Sudano-Sahelian ecological zones, scientists of member countries will screen materials for drought and *Striga* resistance, and related agronomic studies. In order to further improve the Coordination of sorghum improvement research networks in West Africa, an advisory committee was established during the recent meeting of ICRISAT and SAFGRAD joint Sorghum Workshop that was held from 22 to 24 September, 1985 in Bamako, Mali.

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3 Drought and the farming sector: Loss of farm animals and post-drought rehabilitation

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Introduction

This paper examines the effects of drought-induced livestock losses on crop production and considers a range of policy measures aimed at rehabilitation of the farm sector in the post-drought period. Farm animals play an important role in crop production in a number of farming systems. Draft animals are used for ploughing and weeding fields and for transporting goods and people. Female stock provide the household with supplies of milk while animal dung is a source of fertiliser and fuel. Livestock also represent a valuable asset for the farm household, the loss of which makes it poorer and more vulnerable to adversity.

The paper focusses on policies which can be carried out in the short- to medium-term to reduce the length of time taken for the farm sector to recover its productive capacity after drought. It assumes that losses of a certain magnitude have already taken place and thus does not consider the role of pre-drought or emergency measures, such as early warning systems or provision of famine relief. Rehabilitation is taken here to mean the re-establishment of productive farm capacity in drought-affected regions. This may not always imply the restoration of the production system as it was before the drought. For example, very heavy grazing pressure from oxen and other stock may mean that alternative sources of draft power should be found or fodder crop production be increased.

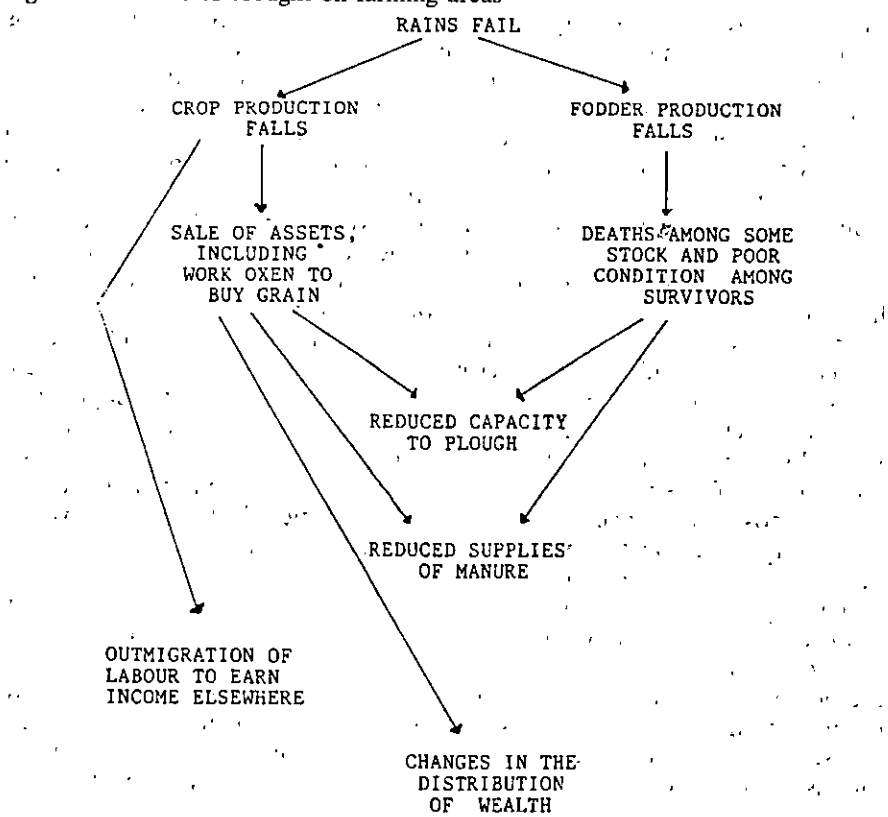
Since the main focus of this paper is on livestock-related aspects of farm production, it will not consider explicitly the need to provide seed and other inputs in order to help farm recovery. However, it is recognised that seed distribution may be a pre-condition for successful post-drought recovery where crop losses have been high. There are also important interactions between the farm and livestock sectors which need to be examined. Drought losses in the pastoral sector affect farmers through changes in the supply and prices of stock. In addition, policy measures taken to aid recovery in the pastoral sector may have spillover effects on the farm sector and vice versa. An example of this is where farmers are given credit to buy young oxen to replace those they have lost, a programme which is likely to have an inflationary effect on the price of such animals leading to a rise in prices received by pastoral herd-owners.

The paper starts by outlining the main effects of drought on crop producers in order to show the various processes through which impoverishment of farmers and losses of stock take place. Next it considers the interaction between droughts in the arable and livestock sectors before looking at indigenous strategies for rehabilitation pursued by producers themselves, following drought losses. It then examines the various policy options open to governments and development agencies wishing to speed recovery in the crop sector and discusses the relative costs and problems associated with each. It will be seen that the most effective form of intervention will depend on the special circumstances found in the region concerned. The paper ends by recommending that priority be given to examining the different options available in a given case and to funding a programme that can be put rapidly into effect.

Effects of Drought on Farm Production and Livestock Holdings

The main direct effects of drought on the farming sector are summarised in Figure 1. The most immediate consequence of drought is a fall in crop production, due to inadequate and poorly distributed rainfall. Farmers are faced with harvests that are too small to both feed their families and fulfill their other commitments. Livestock sales act as a buffer in times of hardship, farmers disinvesting in these assets to buy food. The first animals to be sold are usually those which make the least contribution to farm production, such as sheep and goats. However, as the period of drought-induced food deficit lengthens, farmers will have to start selling transport and draft animals, such as oxen and donkeys, as well as breeding stock, which constitute the basis of the household's wealth. In the Ethiopian highlands, stock are usually disposed of in the following order: sheep and goats, then younger cattle, horses, donkeys and work oxen being sold as a last resort (Wood, 1976), since the latter are essential for land preparation.

Figure 1 Effects of drought on farming areas



Where crops have been badly affected by drought, fodder is also likely to have suffered, although output from natural pastures tends to be less vulnerable to drought than crop production. Low rainfall causes poor pasture growth and may also lead to a decline in fodder supplies from crop residues. Insufficient levels of fodder around the village lead to weight loss and increased deaths among stock, especially where immigrant herds put further pressure on limited local pastures. While the response of most pastoral groups to fodder shortage is to move themselves and their herds elsewhere, this is not an option so easily followed by livestock-owning farmers. Typically, farmers own fewer animals and have less familiarity with regular transhumance than pastoralists, both of which act as constraints on migration. In addition, few farm households will have sufficient labour to both take their animals to other grazing areas and continue with necessary farming operations. Thus sedentary herds can be particularly badly hit in times of drought. A recent survey of deaths among draft animals in the Niono area of north-west Mali found losses of between 50 and 70% over the period 1983–84 (FAO, 1984). These high losses were caused by pasture shortages exacerbated by herds from further north on their way to southern pastures, by the sedentary character of livestock holdings amongst farmers in this area and by the normal dependence of horses (and to some extent donkeys) on a daily grain ration to supplement natural grazing, a supplement which is no longer given because of poor harvests.

The overall effect of a fall in fodder and crop production is to reduce the draft capacity of the farming sector, leading to lower crop output in the subsequent farming season. Loss of livestock around the farming settlement also reduces the household's access to dung, a product of considerable importance both as a fuel where firewood is scarce and as a means to retain fertility on regularly cropped soils.

The role and importance of dung varies between farming systems according to a number of factors. Shortage of fuelwood makes dung a highly valued commodity in many parts of the Ethiopian highlands where other sources of fuel are scarce. Dung is estimated to be the second most important product gained from livestock after draft power in such areas, providing 80% of the household's fuel needs (Gryseels and Anderson, 1983). In addition, sales of dung cakes make a contribution to cash incomes. In many parts of West Africa, dung is a major element in the exchanges established between pastoral and farming communities. Transhumant herders agree to station their animals overnight on farmers' plots in return for grain, cash or water. This manuring of fields produces a considerable increase in crop yields and is of especial value in marginal farming zones in the Sahel as it enables a larger area to be sown with rapid maturing crop varieties. Drought affects the availability of dung to the farm household in two ways. First, the number of animals owned by the farming population falls with death and sales among stock. Second, drought both reduces the size and changes the pattern of movement among pastoral herds. In the Sahelian context, drought conditions will force many herd-owners further south than normal in their search for fodder and water. Farmers in the southern Sahel, who regularly rely on visiting herds for supplies of dung will find their access to this commodity greatly reduced in a drought year. By contrast, yet further south, dung supplies will increase for those farming communities in savannah areas which are host to immigrant pastoral herds in a drought year.

Although they could not be considered as a loss to the national economy, to the individual farmer drought-induced distress sales of work oxen are as much of a loss as are animal deaths. The distribution of work oxen losses between deaths and distress sales will vary according to the circumstances in which drought has taken place and the constraints faced by different producers. A report by the Relief and Rehabilitation Commission of Ethiopia for the province of Wollo in 1974 presents data showing almost all losses to have been due to deaths rather than sales: 71% dead from starvation, as opposed to 19% sold, leaving 2% disposed of by other means and 8% remaining (Wolde Mariam, 1984). By contrast, Wood's survey of farmers in the northern highlands of Ethiopia in 1974 found that most livestock losses were the result of distress sales in order to raise cash rather than deaths due to inadequate fodder (Wood, 1976). As will be discussed later, the circumstances in which oxen are lost have differing implications for the action that governments or agencies should take in moderating the effects of drought.

One means by which farm households try to make ends meet in times of crop failure is to release labour to earn income elsewhere; at the same time, this reduces the burden on household food reserves. The net effect on farm productivity depends on whether this migration continues into the next farming season, thereby reducing the household's labour supply. This will be the case where shortage of food is so acute that the household must depend on the earnings of some of its members to feed the rest of the family until the next harvest.

Changes in the distribution of wealth usually accompany drought. The experience of farm households will differ according to their ownership of assets, their access to incomes from other sources and the extent to which these assets and incomes are less affected by drought than are harvests. The most vulnerable amongst those hit by drought will be those with few assets of value to sell, those who most need to purchase grain due to an absence of their own household reserves and those who cannot gain access to food through other means, such as borrowing, coercion or theft. The richest members of the community may even be in a position to benefit during drought, as they can acquire land and other assets at low prices from distress sales by poorer neighbours. The differential impact of drought on the incomes and assets of rich and poor is formalised by Sen in his essay on "Poverty and Famines" (1981). He showed an individual's entitlement to food depends not only on direct output of crops, etc. but also on his access to food through the market, by the sale of labour or other commodities and through non-market mechanisms, such as redistributive systems within society. In times of drought, not only is there a direct shortfall of food production but also relative price movements of grain versus other commodities may drastically reduce the purchasing power of groups. This is seen in the case of pastoralists who face rising grain prices but falling livestock prices as drought intensifies. Many farmers may be in a similar situation, needing to sell livestock, labour or land in markets where an excess supply of these commodities has reduced their value.

The Interaction Between Livestock and Arable Droughts

A given rainfall shortage is likely to affect livestock and cropping sectors differently. In areas where crops and animals occupy the same ecological zone, farming is likely to be a more risky business, herds being able to compensate for localised rainfall shortages by movement to better favoured areas. Thus, droughts hitting crop production are reckoned to occur more frequently in Botswana than are those seriously affecting the livestock sector. In the case of the Sahel, however, the farm sector occupies the higher rainfall zones to the south of the main pastoral areas. Since rainfall variability becomes more marked as one moves north and as rainfall totals decline, the pastoral sector is particularly prone to drought.

Account must be taken of the interaction between drought losses in the crop and livestock sectors for two reasons.

(i) Grain forms an important part of the pastoral diet even in normal times. In periods of drought, as herd productivity falls, herders come to rely even more heavily on grain for their food needs. Where both the livestock and farm sectors have been hit by drought, rising demand for grain by pastoralists is confronted by a drop in locally available supplies. Given the low elasticity of demand for grains, the increase in market demand from farmers and herders will result in a rapid escalation in prices. If drought has only hit the livestock sector, grain prices will be subject to much less upward pressure.

(ii) Farmers often own a number of livestock, which provide them with draft power and represent an investment to be sold in times of need. Where drought has hit both the livestock and farming sectors, livestock prices will fall further and farmers will be faced with a greater fall in the value of their livestock assets. A few farmers may however benefit during a period of widespread drought if they are fortunate enough to have sufficient stocks of grain from previous harvests to invest in livestock purchases while relative grain to livestock prices are in their favour.

Farmers' Own Methods of Rehabilitation

Policy makers should assess the capacity of crop and livestock production systems to rehabilitate themselves in the absence of outside intervention for two reasons. First, one must have some measure of expected rates of rehabilitation against which to evaluate the impact and cost of various forms of intervention aimed at boosting recovery. Second, indigenous strategies in the post-drought period provide policy-makers with guidelines as to processes of local adaptation which may be given support. Communities often display considerable resilience in the face of drought, enabling them to survive severe crises and to regain their capacity to produce in the subsequent period. The policies of government and development agencies can either re-inforce the effectiveness of these strategies or render them less viable. For example, temporary migration of labour from rural areas is pursued on a regular basis in many countries and provides households with an off-farm cash income. In times of drought, this migration flow becomes especially important, as it both reduces the number of people to be fed from village grainaries and provides a supplementary income for buying food. Government policy can either aid or hamper this flow of labour from poor to better-off regions, by minimizing the bureaucratic obstacles to and cost of movement or, conversely, it can make it difficult for people to travel across regional and national frontiers and obtain temporary employment.

Speed of Farm Rehabilitation

The main concern of this paper has been to investigate the effects of drought-induced livestock losses on the farm sector. The significance of a given level of draft animal losses on farm production will depend on the nature of the farming system and the effectiveness of different strategies pursued by farmers in order to maintain crop output. To assess the likely fall in crop output due to draft animal losses, questions such as the following must be answered:

(i) what proportion of land is normally prepared and weeded by the plough?
(ii) how much time is available for land preparation before sowing?
(iii) what is the effect on yields from late sowing, from sowing on unploughed land or from weeding by hand rather than by plough?
(iv) can land be prepared by hand and, if so, what is the area that can be dealt with?
(v) what proportion of households have the necessary animals and equipment for their own ploughteam and what are the possibilities for sharing of oxen between households?

This paper focusses attention on three countries: Ethiopia, Botswana and Mali, where draft animal power plays an important role in farm production. The significance of work oxen losses will vary between these countries because of differences in soils and in the volume and timing of rainfall within the cultivation season. For example, the heavy soils found in highland Ethiopia must be worked 4 to 6 times in order to obtain a fine enough seedbed for the traditional teff crop. This is in marked contrast to the very rapid ridging of light sandy soils done by many farmers in Mali prior to sowing millet and groundnuts. For highland areas of Ethiopia, the short rains of February to April usually provide the opportunity for much land preparation to take place before fields are sown in June when the main rains begin. In arable areas of Botswana and the Sahel, time available for land preparation before sowing is much more limited and part of the Sahelian millet crop is consequently sown on unploughed land, despite the severe weeding problems associated with this technique.

Ways in Which Farmers Can Achieve Crop Recovery

There are a number of options that farmers can pursue in order to restore levels of crop production and their holdings of draft animals. These include the sharing of animals between households, use of other stock for pulling the plough, hand cultivation of soils, hire of tractor services, changes in crop composition, purchase of fertiliser, supplementation of remaining stock, turning to income earned elsewhere or waiting for livestock holdings to re-grow. Each of these is discussed below.

Sharing of animals between households may be possible where overall losses have been slight. Such animal loans are common in many farming systems in normal years, the loan of a ploughteam often being repaid with so many days of weeding labour. Alternatively, two households with a single ox each can arrange to take turns in using the oxen pair, as described by Gryseels and Anderson (1983) for Ethiopia. However, where oxen losses have been heavy, loans will be less easy to arrange for those who have lost their draft animals and the cost of such loans are likely to increase.

The use of other animals for draft may be possible where, for example, losses among horses and donkeys have been less severe than work oxen. The former will have a lower productivity but their availability will partially compensate for the loss of trained oxen. In extreme cases, even human labour has been used for pulling the plough, as in the period following the great rinderpest epidemic in Ethiopia in the 1890s when an estimated 90% of the country's draft oxen were lost (Wolde Mariam, 1984). However, if work oxen holdings have been badly affected by drought it is likely that other stock will also have suffered high mortality or will have been sold to purchase food grains.

Hand cultivation of part of the farmer's land may be possible in the absence of draft animals. However, this will be at the cost of lower crop output due both to the smaller area cultivated and the lower effectiveness of hand cultivation as opposed to plough techniques. Estimates of the land area which can be cultivated by hand vary from 10% to 50% of that which can be managed by a plough team, depending on the nature of soils and the time available for land preparation. Where weeding is also usually done by plough, resort to hand techniques will lead to lower yields from the less optimal timing of this operation.

The hire of tractor services is only open to a limited number of farmers with access to this service at reasonable cost. Hire of a tractor is usually more expensive than hire of a ploughteam for the same work and, in the case of Botswana, will normally require a cash outlay rather than repayment in labour or other services (Vierich and Sheppard, 1979). For this reason, farmers who find themselves without work oxen will often also be without the funds to hire a tractor.

A change in the composition of crops grown can reduce the farmer's tillage requirements. For example, in the case of Ethiopia, while teff needs a finely prepared seed bed, pulses can be sown on land that has received a more rudimentary tillage. Similarly, in Mali, millets can be sown on unploughed land whereas groundnuts require a prepared seedbed. The possibility of farmers moderating the impact of draft animal losses by switching to less tillage-intensive crops depends on their access to seed, their family's consumption needs and the prospects for marketing different crops.

Fertiliser purchases can moderate the fall in crop output arising from a decline in area cultivated by raising yields on the area actually farmed. The effectiveness of this option depends on crop response to fertiliser use and the relative costs of purchase, transport and application of fertiliser. Lack of cash at the farm level in the post-drought period prevents this option being widely pursued, in the absence of extensive government subsidies for the purchase and distribution of this input.

Surviving draft animal may be given supplementary feed in order to increase their working capacity. This fodder could come from crop by-products or natural pasture and browse, both of which are likely to be in short supply following drought. Additional feed may be available from agro-industrial by-products, such as cotton seed, molasses and bran. Supplies of these products will be limited and their prices high where these are normally exported, (as in the case of many Sahelian countries) unless the government gives special priority to their local use.

Incomes earned elsewhere can be used to buy replacement oxen. For example, migration earnings are a major source of cash incomes for many farming areas in southern Africa and the Sahel. Migration may be seasonal or involve the absence of a male household member for a number of years, during which time cash remittances are sent back to the farm sector for the purchase both of food and farm inputs. The ease with which these earnings can be used to finance the purchase of new work animals depends on the relative value of the remittance, the price of work oxen and the urgency of other calls upon cash income. In times of drought, urban labour markets are usually flooded with job-seekers leading to low real wage levels. For this reason, the size of migration earnings is likely to be low in the post-drought period and possibilities for acquiring the funds to purchase work oxen more limited than in normal times. It will also be harder for farmers to rebuild work oxen holdings where both the arable and the farm sector have been hit by drought. In this case there will be heavy demand in the post-drought period from both the farming sector and the meat market for the limited supply of young male animals and prices will rise accordingly.

Waiting for the herd to re-grow is an option for those farm households with sufficient breeding animals. The speed of recovery in work oxen numbers will depend in this case on the number of oxen required for ploughing, the size of the breeding herd and its rate of increase. However, some arrangement must be made in the intervening years either to obtain food or to borrow draft power from elsewhere.

The speed with which harvests recover and holdings of draft animals are reconstituted depends on the factors discussed above. This process of reconstitution will be more rapid where:

- sharing of animals provides a temporary means by which those without draft animals can continue to cultivate all of their land,
- the agricultural sector is sufficiently productive for farmers to have access to a regular surplus for investment and where the relative price of crops to oxen is in favour of the former, so that a good harvest can enable the farmer to replace lost animals in a single year.
- there are external sources of income which can be used to buy new animals and equipment and to provide for the household's food needs in the intervening period.

Conversely, rehabilitation will be slower the heavier are oxen losses, the greater the area affected by crop and livestock losses and the higher the price of oxen relative to crop output and migrants' earnings.

Data on the Speed of Post-Drought Recovery

Post-drought surveys provide some data on the evolution of harvests over subsequent years and of the time taken for crop production to get back to normal levels. However, there are often a number of other factors affecting total harvest size in the post-drought period which make it hard to assess the relative importance of work-oxen losses as compared with variables such as lack of seed, rainfall levels, social and political dislocation, etc.

The drought year of 1978/79 in Botswana saw an estimated 60% fall in area cultivated in the region surveyed, caused by the poor condition of work oxen and the poor timing of rainfall at the start of the farming season.

However, the following season appears to have seen an increase in area cultivated above normal levels, farmers having an incentive to increase their field size, given shortages in food supplies (Jones, 1980). This increase in area following the drought was made possible by the relatively low losses (of 10-15%) suffered among draft animal holdings and the extensive systems for loaning draft power between households.

In the case of the Sahel, no material is available on the speed with which area cultivated returned to normal after the drought of 1968-73. However, grain production figures would suggest that harvests were back to pre-drought levels in 1984, which would imply no significant adverse impact on farm productive capacity as a result of the drought. This may be explained by the relatively low losses of harvests and oxen in most farming areas, so that area farmed and output could return rapidly to normal once rainfall conditions improved. By contrast, recent material from north-west Mali would suggest a fall in area cultivated of between 30 and 50% in 1984, due to heavy losses of draft animals the previous year. Even with the return to better rainfall in 1985, such farming areas cannot hope to obtain a reasonable harvest.

For Ethiopia, data on crop output and area cultivated is scarce for the periods surrounding the droughts of the early 70s and those of 1982-1984. Wolde Mariam (1984) cites a report for Wollo and Tigre in which previous losses of work oxen are held to account for between 44 and 87% of the cases in which land was not cultivated in 1973, with seed shortages mentioned as being of only secondary importance. Crop production figures suggest that 1974 saw a return to more normal levels of output at the national level but these figures should be treated with care as they refer to national output rather than to that from the most drought-affected provinces. In subsequent years, additional factors, such as land reform, and political instability have themselves contributed further to difficulties in assessing changes in farm output for the drought-prone areas of Wollo and Tigre. Data for crop production in 1985 is patchy and it is difficult to separate the effects of work oxen losses from the other major influences on the level of farming activity in different regions of the country.

Policy Measures to Aid Recovery of the Farm Sector

This section will consider the alternative policy options open to governments and development agencies aimed at speeding the recovery of farm production after drought. As in the rest of this paper, it focusses on livestock-related aspects of crop production. Thus, it does not consider explicitly the need for seed provision, although access to seed is evidently a precondition for restoring production levels.

Policy options can be divided into three categories: those that enable the farm sector to help itself, such as lowering rates of taxation; those that aid the farm sector by the direct provision of inputs, such as credit to buy oxen and fertiliser; and those which, though directed at the livestock sector, nevertheless have a beneficial effect on farmers' ability to reconstitute their draft animal holdings. Within each category, there are certain actions which are properly the domain of the national government, such as pricing and taxation policy, while others are open to both governments and agencies to undertake, such as the funding of a credit programme.

Policies differ with respect to their cost, their impact on different producer and consumer groups, their effect on the external trade balance, their spill-over effects into other sectors of the economy and the speed with which they can be implemented. These different impacts should be taken into account by decision-makers before deciding which options to pursue. In addition, governments will find that the probability of receiving external funding differs between policy measures, donors being more willing to fund direct interventions in farm production than to provide general financial support for the government budget.

Several policy options considered below involve government intervention in controlling prices, trade flows or providing subsidised inputs to the farm sector. These policies presuppose a structure through which governments are able to act effectively at little extra cost. In practice, the absence of the necessary degree of government control limits the likely effectiveness of certain measures. For example, where the government has little control of livestock exports, due to long frontiers which are costly to police, measures to ban exports of certain classes of stock are unlikely to be very effective. Finally, all policy options need to be compared with the cost of not taking any action and the consequent need for famine relief provision.

Government Policy Measures

Several policy instruments are considered here: changes in taxation of the farm and livestock sectors, increases in crop and livestock prices, minimization of constraints on labour migration from rural areas and controls on animal exports. The main aim of these measures is to reduce the pressure on farm incomes and thereby allow a more rapid return to pre-drought levels of production.

(a) A reduction in poll or land tax helps recovery as it leaves the farmer with more disposable income for investment in new animals and farm equipment. Changes in the level of taxation on cattle will have a less clear-cut effect. To the extent that the farmer owns livestock, a tax reduction per animal head will be of benefit. However, such a reduction will also reduce the pressure on herders' incomes and their need to sell stock, leading to lower supply of and higher prices for livestock. This will be to the disadvantage of farmers wishing to purchase animals to restore their work oxen holdings. Tax cuts have the advantage of being speedy to implement. However, they do cut government income and, in the case of a simple tax cut for all producers, do not differentiate between the better-off and those truly in need. A tax system able to direct benefits to a more specific target group would be more complex and costly to implement.

(b) Where the government controls the price and marketing of major crops, resources can be channelled to the farm sector by *raising farm prices*. However, the scope for this policy measure is probably fairly limited, first because farmers who have lost their draft animals are unlikely to have a significant crop surplus for sale and second, because the government will be very reluctant to increase the cost of food to urban consumers. Government attempts to manipulate livestock prices, in order to help farmers purchase new work oxen, may also be of limited value given the large proportion of domestic and external trade which passes through unofficial channels in many countries.

(c) *Minimising the constraints on rural migration* was noted earlier as a way that governments can help indigenous efforts at rehabilitation at little or no cost. The degree to which migrants' earnings can contribute to rebuilding farm assets will depend on the relative supply of and demand for labour in areas receiving immigrants, which will in turn depend on how extensive the drought has been.

(d) Several countries have imposed *controls over the export of livestock* following drought, in order to retain some animals within the national herd and to moderate upward pressure on domestic livestock and meat prices. The effectiveness of these controls will vary, given differing capacities to direct animals through official channels. However, even where it is relatively easy to evade border controls, the imposition of an export ban on stock is likely to depress prices to a certain extent. The greater the downward effect on prices, the more farmers will benefit from being able to buy cheap animals for draft.

Direct Help to the Farm Sector

There are several ways in which governments and agencies can mitigate the impact of workoxen losses on farm production. Some of these policies have been pursued in the past in Ethiopia and Botswana while others are currently being undertaken. Here, the options will be compared in terms of their relative costs and the particular problems associated with the implementation of each. Details of each option are presented in Table 1. Data on costs are taken from a number of different sources, referring to interventions at different dates and for differing localities. They should thus be treated with caution as they indicate rough orders of magnitude rather than precise costings. Their utility lies in presenting the kind of rapid calculation of returns from alternative policy options which governments and agencies need to do in order to identify the best course of action in a given situation.

(a) *Work oxen credit to farmers* involves the issue of loans to farmers, in cash or in the form of animals, for repayment over a period of years. A number of work oxen credit schemes have been carried out in different countries within general programmes of agricultural development, but few have had the restoration of drought-induced oxen losses as their explicit objective. One of the few examples of the latter was that pursued by the Ethiopian government over the first 6 months of 1974, during which an estimated 40,000 loans were given out to farmers in drought-affected regions (EPID, 1974). Following the 1982-84 drought in Ethiopia, a number of agencies have also been involved in distributing oxen to farmers, either on credit or as gifts.
A number of questions are raised by work oxen credit schemes.

First, what are the possibilities for distributing one ox per farmer rather than a full team, with a view either to farmers sharing their animals or to the introduction of single ox cultivation techniques?*

Second, what are the number of oxen available for purchase, either within the region or in neighbouring rangeland areas and what are their relative prices in each case, including transport costs?

Third, how satisfactory are the grazing resources in the region which is to receive the oxen? In the absence of natural pastures, the cost of providing alternative supplies of fodder for example by keeping oxen in neighbouring

* As developed by ILCA, see ILCA Bulletin no. 18, pp: 20-25 and ILCA Newsletter vol. 5, no. 1, 1986.

Table 1 Draft power policy measures: a comparison of alternatives

Project	Initial Cost	Associated Cost to government/agency	Area cultivated US$100 spent	Issues Arising
(1) Work oxen credit to farmers	Loan for oxen purchase of US$140-180 per ox	Administration, vaccination, insurance, fodder	1.00 – 1.50 ha.	Oxen available locally? fodder supplies adequate?
(2) Government tractor pool	Purchase of tractor at US$15-20,000	Fuel, spare parts, skilled labour and administration	2.00 – 3.00 ha.	Soils and terrain suitable?
(3) Loans for local tractor hire	Loans to farmers at US$20-40/ha.	Administration. Other costs borne by tractor-owner	2.00 – 4.00 ha.	Tractors available locally? Soils and terrain suited?
(4) Hand tool distribution	Purchase of tools at US$5 per unit	Distribution, high labour cost	2.00 – 10.00 ha.	Variability in soils means wide range in possible area farmed
(5) Fertiliser distribution	Purchase at US$60 per 100 kgs.	Transport and distribution	Raise fertility on 1.00 – 2.00 ha.	Expected crop response known?
(6) Supplement surviving work oxen	Purchase feed at US4-8c/kg, feed 2-3 kgs over 90 days/per ox	Transport and distribution	1.00 – 5.00 ha.	High return depends on selecting oxen most in need. Extra land available?

Notes

(1) Assumes oxen pair can work 3.00 – 5.00 ha of land. This is high for the Ethiopian context but relatively low for conditions in the Sahel and southern Africa.

(2) Assumes a minimum of 250 ha. ploughed per year per tractor and annual running costs of around US$10,000, including depreciation.

(5) With assumed increase in output of 200-400 kgs/ha., return on fertiliser purchase is from US$60-120 (grain valued at US$300-400 per ton, as noted earlier).

(6) Total cost of supplementation is US$20-45 per oxen pair. Assumes that following this supplementation, oxen pair performance raised from 1 ha. to 3 ha.

areas where pasture conditions are better or by transporting fodder to animals in pasture deficit areas must be considered. The latter is likely to be considerably more expensive than other options. The long-term availability of fodder must also be considered. Where the pressure of human and livestock populations is already very great, decision-makers should consider the possibility either of increasing fodder production, through increased cultivation of forage crops, or of replacing oxen as the main source of draft power with mechanised techniques.

Fourth, should farmers be given a cash loan with which to purchase oxen or should oxen be distributed directly? There are many advantages to the farmer being the purchaser of his own ox. He makes the choice among available animals and thus is not forced to take an animal which he feels to be unsuitable for any reason. In addition, farmers will have a good knowledge of local opportunities for the purchase of oxen not readily available to project staff. The overall effect on oxen prices of a large number of purchases by individual farmers spread over a period several weeks or months, is likely to be lower than that of a large scale operation by a project agency. On the other hand, agencies may have access to sources of animals at lower prices from more distant areas which cannot easily be reached by individual farmers. However, transport costs will be higher when oxen must be brought in from far away. In addition oxen taken from a different rainfall and ecological zone may find it difficult to adapt to grazing conditions and diseases in the farming region to which they have been brought.

The granting of loans directly to farmers does increase the risk of fraud, as it will be hard to monitor whether the ox presented by the farmer as having been bought with the loans was in fact bought, or whether it has been borrowed from a neighbour or was already owned etc. A certain level of fraud is probably acceptable if it keeps down administrative costs and allows a large number of individuals to be reached quickly. Also, fraud involving the use of funds by needy recipients for purposes other than those intended is of much less importance than fraud involving the diversion of cash to those not truly in need.

Fifth, should oxen be distributed on credit or as an outright gift and, if the former, what should be the terms of loan repayment? There may be circumstances in which the option of making a gift of the stock should be seriously considered, as where the cost of collecting loan repayments is going to be high and will absorb scarce administrative capacity. Where there are considerable risks to stock there is also an argument in favour of gifts rather than loans as, in the case of future drought, farmers will be faced with great difficulty in repaying loans. On the other hand, repayments can be used to form a revolving fund providing further credit to farmers, thus widening the spread of benefits from the original provision of funds.

In the case of loans, the project must decide on the terms of repayment. If loan repayments are set too high, farmers may be unable to save sufficient surplus to invest in the new draft animals essential to the long-term rehabilitation of the farm's productive capital. The various schemes involving work oxen credit programmes which have been carried out in East and West Africa have had repayment period of between 3 and 5 years, an upper limit on the length of the repayment period being set by the increasing risk of death as animals age. Repayments on the credit scheme run by EPID in Ethiopia following the 1972-73 drought were to be made over a 4 year period. However, very few of these loans seem to have been subsequently repaid, given continuing drought in some areas and the political uncertainty following land reform.

(b) *Government-run tractor pools* are based on the government purchasing a fleet of tractors which are then made available to farmers for a fee. Benefits from such a scheme will be greatest where the terrain is suited for tractor cultivation, that is, not too hilly and with few rocks and tree stumps, and where oxen and pasture shortages are so acute that no alternative sources of draft power can be considered. The costs of such schemes are likely to be substantial, given the high foreign exchange cost of purchasing the tractors, and of the spare parts and fuel which will be needed for their operation. The cost of providing skilled labour, necessary for the operation and repair of equipment, will make yet further demands on government funds. Shortages of any of the inputs required to keep the tractors in working order will increase the risk and the cost per hectare of pursuing this option. At the time of the EPID programme in Ethiopia in 1974, the cost of setting up a tractor pool was estimated at E$20,000 per tractor, in comparison with a cost to the farmer of E$60-70 per hectare if tractors were rented from large farmers. The establishment of a government-run tractor pool would only be cost-effective:

- if each government tractor could plough a sufficient number of hectares to bring the per hectare cost close to that of the private sector.
- if the value of dry season work by the tractor pool, such as the transport of goods, is sufficiently great to compensate for a lower level of ploughing capacity in the farming season;
- and if the available draft capacity from other sources is so low, whether from oxen or from locally-owned tractors, that the relevant comparison which should be made is not that of the relative costs of preparing land by alternative techniques but rather the cost of ploughing using government-owned tractors versus the cost in foregone output of the land not being cultivated at all.

While schemes for providing draft power to farmers after drought have focussed on the use of tractors, there may also be alternative mechanical options worth considering, such as small rotary cultivators which can be used on steep plots of land.

(c) *Loans for the hire of local tractor services* are an alternative in some circumstances. For example, in Botswana, even in normal years, farmers regularly hire tractors belonging to others in order to prepare their land. The governments of both Botswana and Ethiopia have in the past granted loans to farmers for hiring tractor power to compensate for drought losses among oxen. The cost of these has varied from US$20-40 a hectare, which the farmer is supposed to repay after the harvest. Evidently, the feasibility of this scheme depends on the number of tractors available within a reasonable distance, their spare working capacity and the suitability of farmers' plots to this ploughing technique. There will be costs in the form of fuel, spare parts and skilled labour requirements but these will be borne by the tractor-owners rather than the government. The main disadvantage of this scheme is that it does not provide farmers with a renewal of their productive capacity and they will need to find help from this or another draft source in the years to come.

(d) *Provision of hand tools* is a low cost way to provide households with the means to farm their land. The viability of this option depends on how much land can be cultivated by hand in comparison with the plough and on the associated decline in yield per hectare. The extent to which yields will be lower for hand- as opposed to ploughteam-prepared and weeded land will be determined by the importance of timely sowing and weeding, by the area of land cultivated per worker and the consequent tightness of land preparation and weeding constraints. Where each worker farms a large area and where seed must be planted early to ensure a reasonable yield, preparation of land by ploughteam may be the only effective way of sowing and weeding. For example, under the extensive farming practices of central Mali, where the area per worker can be as high as 305 ha., ploughteams play a major role in achieving high yields of millet per worker, as they permit a very large area of land to be sown and weeded within a rainy season lasting only 6 to 8 weeks (Toulmin, 1983). Farm households without their own ploughteam must borrow equipment from others, often only available rather late in the season and they suffer lower yields as a result, due to sowing much of their grain on unploughed land and to the slowness of hand weeding.

In Ethiopia, land holdings are often smaller than in the Sahel, with each household farming on average between 2.0 and 2.5 ha in the highland region.

While this would lead one to expect a greater potential role for hand preparation techniques, soils are so heavy that hand preparation of land is actually extremely rare, being limited to the steepest hillside plots. Given these soil conditions, farmers resorting to hand tools would probably face a significant fall in the area they could cultivate.

Besides the fall in area cultivated when hand techniques are used, there are two additional costs from the use of hand tools. First, soil preparation is likely to be less effective using hand tools, leading to less successful seed germination, more competition from weeds and hence lower yields per hectare. Second, the work involved in hand preparation is very considerable and would make demands on household workers at a time when energy and food reserves were already very low.

(e) *The provision of fertiliser by donors* as a complement to hand tool distribution could be considered, the increase in fertility would partially compensate for the fall in area cultivated and the lower yields per hectare associated with use of hand tools. Disadvantages to this option include the foreign exchange cost, if funded from government resources, of fertiliser imports and the high costs of transport and distribution to areas of need. To assess the likely effectiveness of this option one needs to know the expected crop response from the application of a given quantity of fertiliser per hectare. With fertiliser prices of around US$60 per 100 kgs, a price of US$300 – 400 per ton of grain and application rates of 100 kg/ha, crop output would have to rise by at least 150 – 200 kgs/ha to make the scheme financially profitable. However, economic or social profitability would demand a lower percentage increase in yields, taking account of the cost of alternative food supplies for farming populations and the value placed on re-establishing viable farming communities.

(f) *Supplementation of work oxen* aims to improve draft performance by moderating weight loss. The increase in draft power gained from supplementation depends on the relative weight loss of supplemented and unsupplemented stock and on the demands made upon draft animals, in terms of the length of a working day and the tractive power required. Any improvement in performance is translated into higher crop production either through an increase in area or through more timely sowing and weeding. The relative size of each of these benefits is determined by the availability of land with which to increase cultivated area and by the significance of timeliness for final yield. These factors are likely to vary between different regions according to population densities and the pattern and volume of rainfall. Within the Ethiopian context, for example, supplementation of work oxen is likely to lead to improved tillage and more timely sowing of fields, rather than a significant expansion in area cultivated, given the shortage of unoccupied arable land in most farming regions. Benefits from supplementation will be greatest where it is restricted to those animals which have lost a substantial amount of their body-weight and whose subsequent ability to work is much impaired.

A Comparison of Alternative Policy Measures

The fourth column in Table 1 gives the estimated areas which could be cultivated for every US$100 spent on each measure. Based on the data used for the table (summarised in the notes below), there is remarkable similarity between the alternatives in terms of their cost. Given the imprecision of these data, it would suggest that there is little to choose between the options as far as their financial cost is concerned. Policy-makers should consider how the relative cost of each option is likely to compare under the particular circumstances they face. In order to do this, they need information on the following: (i) the prices and availability of grain, oxen, fodder, tractors and fuel in the region concerned; (ii) the suitability of soils for cultivation by tractor or some other machine; (iii) the shadow price of foreign exchange and skilled labour to the economy; and (iv) the expected reponse of crop output to differing levels of input use.

The Cost of Doing Nothing

The cost of taking action to rehabilitate the farm sector after drought should be compared with the cost of doing nothing, which includes the short-term cost of continuing to provide famine relief to the affected population and the longer term consequence for the government and national economy of low levels of agricultural production. The provision of food relief at a basic 0.5 kgs of grain per adult per day implies a total of 900 to 1,000 kgs per annum for a household containing 7 people, or 5 adult equivalents. The cost attributable to providing this grain ration depends on the price of grain, the size of transport costs and on who pays the bill. For example, grain provided free to a particular government for distribution as food aid will cost the government little or nothing, depending on who is responsible for its transport and distribution within the country. By contrast, grain which must be bought on the open market will cost the government dear in foreign exchange and transport costs. Here, the price of grain is assumed to be US$300-400 per ton, based on the cost of either buying local food grains or buying grain on the world market plus transport costs to local markets, the latter probably being as high as US$150-200 per ton for land locked states with poor road networks. Given an average expected yield of 400 kgs per hectare following the interventions described above, it can be seen that all of the policy options give a benefit cost ratio far in excess of unity in a single year, even if no account is taken of the wider social benefits associated with re-establishing production in rural areas. There are consequently very strong arguments in favour of pursuing the rehabilitation of farm production as an urgent priority.

Conclusions

This paper had discussed a range of policy measures aimed at rehabilitation of livestock-related aspects of farm production after drought. It can be seen that there are a variety of policies open to governments and agencies, each with particular cost and welfare implications. Policies also differ in their spill-over effects on the rest of the economy, some being precisely targetted, such as a subsidy to a specific producer group, while others cause widespread changes in the structure of prices and incentives within the economy. Choice between these alternatives will be partially determined by the conditions faced in the post-drought period, in terms of the resource domestically available – such as pastures, livestock, grain and seed – local administrative capacity and the country's marketing and transport infrastructure. External finance from aid agencies can help loosen some of these constraints by, for example, supplementing local food supplies by relief grain.

It would be wise to consider as many policy options as possible, since conditions faced by producers in different regions will vary greatly. For example, where local tractor power is available, government credit or subsidies for tractor hire is an obvious option to pursue, especially where local draft oxen supplies are limited and prices high. In areas where fodder supplies are scarce and highly vulnerable to drought, alternatives to oxen as the main source of draft should be considered. Similarly, while most oxen distribution schemes have involved the provision of credit, the option of given stock should be considered under certain circumstances, where repayment is subject to high risks and high costs of collection.

An assessment of policy options should include the consequences for the affected community and national economy of taking no action. Governments can either continue to provide food relief to drought-affected groups or leave them to help themselves. In either case, there is a cost associated with taking no action, in terms of foregone output, the cost of purchase, transport and distribution of food relief and the longer term social costs from the dislocation of rural communities from self-sufficient production. The rehabilitation options looked at in this paper compare very favourably with the cost of food relief provision and should provide a fast return on invested resources. In this regard, returns are likely to be much higher on projects of farm rehabilitation, involving the re-establishment of production using traditional methods, than those aiming to introduce new crops and technologies to farmers. Where the social cost to affected populations of foregone farm production is also taken into account, the returns from funding rehabilitation, as opposed to relief measures, will be even higher.

Policies for rehabilitation should be linked in future with more effective short-term relief measures and long-term policies for establishing less drought-vulnerable systems. The speedy provision of relief food supplies at an early stage of the drought cycle, to farmers in greatest distress, would reduce the subsequent need for more costly rehabilitation measures. For example, if farmers in areas with sufficient pasture could get access to food relief, they would be under less pressure to liquidate their livestock holdings. There would consequently be more draft stock available and less need for oxen reconstitution programmes in the post-drought period. Rehabilitation policy should also be formulated in co-ordination with longer term measures, since the post-drought period can offer a breathing space within which to initiate changes in patterns of production and resource management. This will be particularly important, for example, in areas where pre-drought levels of livestock had surpassed the capacity of grazing normally available.

In the post-drought period, the shortage of livestock will constrain levels of production in both the cropping and the pastoral sector. Given the importance of these two sectors for many countries in sub-Saharan Africa, careful choices need to be made about the priority to be given to helping one or other sector. The high degree of interaction between the two sectors, through animal and grain markets and competition for scarce fodder resources, means that the effect on pastoral production from intervention in the farming sector should be analysed and vice versa. For example, some competition will exist between the use of male cattle for meat – by their fattening and early slaughter – and their being used for draft purposes. The relative strength of demand for young oxen will depend on the incomes and purchasing power of domestic and foreign consumers of meat and on the investment funds available to farmers. Where drought losses of work oxen have been high, farmers' ability to reconstitute their work oxen holdings will be reduced if they face strong competition for male animals from meat markets. In such cases, some intervention may be necessary to achieve the desired balance between satisfying immediate demands for meat and the requirements for rehabilitating productive farm capital. The provision of credit to farmers to purchase work oxen would have the dual effect of increasing farmers' purchasing power relative to meat consumers while benefitting livestock-sellers by the upward effect on animal prices. In other areas, the two sectors may be in competition for scarce resources as, for example, where a limited supply of feedstuff or veterinary inputs is available for distribution.

A strong case can be made for priority to be given to crop production, given the importance of grain in the diets of all consumers and of the poorest groups in particular. Re-establishing grain production will also benefit livestock producers by bringing down the relative price of cereals to livestock. This will reduce both pressure on herders' incomes and the number of animals needed for a viable livestock holding. However, some resources should also be made directly available to the pastoral sector, given that extensive livestock production is usually the only way to effectively utilise the sparse resources found in many semi-arid regions. Grazing animals convert these resources into valuable products for the rest of the economy as well as providing support to a given human population. The supply of young oxen to the farm sector in future will also depend on the speed with which animal numbers and levels of livestock productivity recover in the pastoral sector following drought.

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4 Agricultural Development Policy and Research in Kenya

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Introduction

Agriculture plays a crucial role in Kenya's economic development, contributing about 35 percent of Gross Domestic Product. About 80 percent of its population is dependent on agriculture for their livelihood. It provides a sizable amount of employment and is a major source of foreign exchange. Besides, it serves the growing market for the foods and services produced by other sectors as well as producing the goods and primary materials on which successful growth in other sectors largely depend. Adverse weather conditions, constraints on land supply, a growing population, sectoral policies and research greatly influence the performance of agricultural sector in meeting the increasing challenges for overall development in the country.

Kenya obtained independence at the end of 1963 and launched its planned economic development in 1964. The development efforts are made under successive Five Year Development Plans. Four Plans have been completed during the period 1964-83. The fifth Five-Year Plan is already in progress.

This paper discusses agricultural development policies in Kenya and evaluates the agricultural performance in terms of structural changes, growth in production and its sources since independence. The gaps in agricultural research are identified and possible areas of improvement are discussed.

Agricultural development policy

Kenya's current agricultural policy has been strongly influenced by history. The policies which were adopted by the colonial government early in this century still have a bearing on the problems faced by the policy makers in formulating development policies. In particular, land tenure and agricultural marketing problems the country faces today have their origin in the colonial period. It is therefore instructive to discuss Kenya's agricultural development policies for the pre- and post-independence periods separately.

The pre-independence policies

From the beginning of the century, Europeans were encouraged to settle in Kenya. About 20 percent of the usable land area was alienated for their exclusive use. Policies were systematically designed for the benefit of these settler farmers. Smith (1976) has provided a good account of most of the policies which were formulated to encourage European settlement. Taxes were levied on the indigenous population in order to secure supplies of African labour for the settler farms. Africans were prohibited from growing high valued cash crops such as coffee, tea and other crops which could compete with the settler producers. The settlers were protected against competition from imports and were offered cheap freight rates for railing their exports to the coast. The infrastructure, including railways and roads were built to meet the settler needs. Marketing boards were established to serve their interests.

During the pre-independence period, African agriculture was largely ignored by the policy makers at the time. The only assistance provided was the attempt to forcibly implement soil conservation programs to avoid famine in the overpopulated areas. However, coersion was met with stiff resistance from the Africans and the programs did not achieve the desired goal. The rising population pressure on a limited arable land base and the inequalities created intensified pressure for change in the policies. By 1949, the Africans had been allowed to grow coffee while by 1952 smallholders had started growing tea.

The Swynnerton Plan, which was published in 1954 had far-reaching effects in the formulation of subsequent agricultural development strategies. The plan aimed at formulating guidelines for promoting development in the African areas. The main components of the Swynnerton Plan were: a major program of land reform, increased availability of agricultural credit, and a reorientation of research, extension and marketing bodies. The Swynnerton Plan remained the basis for colonial policy until independence in 1963 and even thereafter in smallholder areas.

The land reform measures proposed by Swynnerton had three aspects: the adjudication of land to ascertain the ownership rights of the individuals or groups in question, where necessary consolidation of separate fragments of land into single units and registration, to provide owners with title deeds for their land. This reform has remained a major government policy on land use. The reform has taken a long time to complete for even by 1983, not more than 50 percent of the holdings had been issued with title deeds (Republic of Kenya, 1984.)

A number of benefits were envisaged to flow from the reform. These included the provision of legal title deeds which would act as collateral when obtaining loans. Thus, long-term investments to own farms would be encouraged. Moreover, reduced expenditures of money and time in land litigation would have favourable effects on productivity. Consolidation would facilitate crop rotation, waste less walking time, make it easier for cultivators to protect their crops against theft and pests and make it more economical for the government to provide services to individual farms. Also more wage labour was expected to be employed due to the creation of landlessness in the process of the reforms and therefore facilitate poverty alleviation.

The post-independence policies

The development plans since independence have underscored the importance of land reform following the lines suggested by Swynnerton. The implementation, though slow has been on-going and studies such as those of Barber (1970) suggest that the largest proportionate increases in revenue cash crops had occurred in the districts in which tenure reform had advanced furthest. Other studies such as those of Okoth-Ogendo (1976) suggest that the increased output was actually not related to the reforms and that the program had worsened landlessness and created unemployment. Land registration and the issuing of title deeds created the legal basis for a market in agricultural land. The creation of such a market while desirable brought the danger that the well-to-do will buy out poor farmers, resulting in widening disparities in the ownership of land.

Another aspect of land reform has been that of land transfers from the former settlers to the Africans and also the subdivision of large farms to smallholdings. This subdivision has taken the form of cooperatives and land-buying companies purchasing large mixed farms and subdividing the land amongst the shareholders. This subdivision has received government support. It is still too early to predict how this subdivision will influence total output and technology. However, it is anticipated that employment will be generated in this process.

Price intervention policies have also been upheld since independence, although Kenya is not unique in this aspect. The price policies take different forms and are implemented in various ways. The government gets involved in fixing producer prices for essential commodities, setting consumer or retail prices, and providing input subsidies occasionally. The aim of intervention has been to encourage the intensification of land use for both crop and livestock production through the improvement of farming techniques and practices on all farms to raise overall incomes and employment in agriculture. This intensification of land use is associated with a concentrated effort to raise the standard of living of the poorer families in relation to those of the community as a whole. The fourth development plan of 1979/83 for instance focused on poverty alleviation as a development strategy. The plan spelt out provision of basic needs and the creation of income earning opportunities as possible areas which would enable the achievement of the development objectives.

Price control and market regulations in the agricultural sectors also originated from the colonial period. The colonial government supported the large farms of settlers with a variety of policy measures. These included provision of agricultural services, subsidised transport and regulated markets for farmers. Initially, domestic marketing boards were set up with the aim of operating a monopolistic pricing policy in favour of large farmers (Heyer, et al. 1976). In the 1930s, the Wheat Board was established. This was followed by the formation of Kenya Meat Commission, the Maize Board and the Kenya Dairy Board which were set up in the 1950s. Today's involvement of Marketing Boards and other statutory authorities both in food and export sector of agriculture therefore originated from the colonial period.

The current agricultural policy issues

Kenya's agricultural policy is normally contained in the Five-Year Development Plans. In addition, specific Sessional Papers spell out the policies for various subsectors within Agricultural Sector. Those have included the 1980 National Livestock Policy, the 1981 National Food Policy and the 1986 paper on Economic Management for Renewed Growth. The broad objectives of the policies have continued to be: encouraging overall sector growth, improving the balance of payments by meeting domestic needs and expanding exports, increasing employment opportunities, raising rural incomes, conserving natural resources, achievement of food self-sufficiency (guaranteeing minimum nutritional levels and implementing food security strategy). To achieve these objectives, price, marketing and structural policies have been pursued. The implementation of the policies has however been a great problem confronting the policy makers.

Price policies

The allocative function of prices is well known. Farmers in Kenya use relative prices in their production decision and respond quickly to changes in prices by adjusting the inputs to attain maximum profits. For instance, as to whether farmers would grow a cash grop or a food crop mainly depends on the relative prices. A case in point could illustrate this phenomenon. In Western Kenya studies show that higher prices of sugar relative to maize in 1979 caused a shift to sugar production (Meilink, 1985). This led to famine in the area. Thus, although the farmers had the cash, there was no food to buy because the food distribution system in the area was not well developed. This made it necessary to think about food self-sufficiency as a strategy in areas where such distributional problems were evident. The National Food Policy paper of 1981 in fact addresses the issue of food security and points out that food self-sufficiency should be a priority in smallholder farms.

Producer prices for commodities such as maize, wheat, rice, sugar cane, been milk beef, cotton are set by the government. The criteria used takes account of cost of production as well as import and export parity prices. The producer prices for fruits, vegetables and potatoes are determined by supply and demand forces without government intervention. Tea, coffee and sisal prices follow world market prices. Producers receive the export prices minus marketing costs, levies and taxes. Cash crops such as barley and tobacco are set by Kenya Breweries and British America Tobacco companies respectively.

The controlled producer prices are normally set through an annual price review. A single price is established for a whole year and for all geographical regions. This fixed pricing system has been criticised as posing a disincentive for food production. It is argued that a reformed pricing system with a support and ceiling price levels with a marketing board intervening in the market when producer prices rise above import parity price levels or fall below export parity levels will be far much better (Meilink 1985). In fact it is strongly argued that private traders would perform the function of balancing food demand and supply in the country better than the marketing boards. Eventually, there should be a need to relax the strict maize movements within the country.

To enable examination of the price trend for producers, price indices of the commodities have been constructed with 1979 as the base year. These indices are shown in Table 1.

The domestic food crop price trends are a reflection of the Kenya pricing policy. There was evidence of continued increase in the 1979-83 period. These increases would seem to favour producers. However, if examined against prices paid for inputs, the producers actually suffered adverse terms of trade. The terms of trade for the period between 1979-1983 is given on Table 2.

Agricultural marketing policies

Three broad categories of institutions are involved in agricultural marketing. There are private traders, cooperatives and statutory marketing boards. In most areas, local trade is dominated by private and competitive trading in the village markets where small quantities of produce are brought once or twice weekly to be sold directly or through local traders (Awiti 1985). Large cooperatives, originating from the colonial period have been modified to include smallholder participation. Small farmer cooperatives, organised

Table 1 Indices of Gross Producer Prices for Major Agricultural Commodities between 1979 and 1983 with 1979 as Base Year

	1979	1980	1981	1982	1983
Coffee	100	93.5	80.2	98.7	123.9
Tea	100	117.2	130.7	143.0	160.9
Sisal	100	114.7	114.1	139.3	173.1
Sugar cane	100	100.0	109.0	127.8	170.7
Pyrethrum	100	119.3	114.3	114.3	114.3
Seed Cotton	100	100.9	104.0	107.3	112.5
Maize	100	123.4	129.9	139.0	210.4
Wheat	100	113.9	115.9	130.5	154.2
Rice Paddy	100	100.0	99.3	99.3	117.9
Beef 3rd grade	100	115.4	139.3	159.7	170.7
Bacon Pigs	100	110.4	125.3	176.5	271.0
Milk	100	110.6	140.9	162.9	181.8

Source of primary data: Republic of Kenya, Development Plan 1984-88, 1984.

Table 2 Terms of Trade Indices for Agriculture, 1979-1983: with 1976 being the Base Year

	1979	1980	1981	1982	1983
Prices received					
Total Crops	116.4	122.3	129.7	138.0	152.7
Domestic	115.9	130.7	141.3	147.8	159.3
Export	116.8	117.4	112.3	134.6	158.1
Livestock Products	135.6	140.6	151.2	166.7	178.6
General Index of Agricultural Prices	123.1	133.1	145.8	159.5	183.4
Prices paid					
Purchased inputs	124.5	137.9	153.3	182.1	192.6
Index of purchased consumer goods – rural areas	130.1	146.1	169.9	205.5	234.4
Indices of prices paid	128.7	144.1	165.8	199.7	224.0
Agriculture Sector Terms of Trade	95.6	92.4	67.9	80.0	81.9

Source: Republic of Kenya, Development Plan 1984-88, 1984.

more recently enable farmers to market produce like coffee, milk, butter and cotton. Apart from collecting, processing and transporting farmers' produce, most of these cooperatives also perform other functions such as the supply of farm inputs and provision of seasonal credit.

Marketing boards are set up by the government to organize and control the marketing of specified agricultural products. The boards vary in regulatory and marketing functions, depending on the government's objectives with the crop or product concerned. Apart from marketing, tasks, some boards like those of coffee and tea also undertake development activities by supplying inputs, extension services and conducting agricultural research.

Structural policies

The major policy issue regarding the structure of farms is that of subdividing the former large scale farms into economical units. This is aimed at raising employment and production in hitherto unutilized or underutilized land. Other issues included in this category of policy is the land reform program which began in the 1950s and is on-going. With the rising population, these structural policy issues become very important if the cultivated land has not to be subdivided to uneconomic units, especially if everyone wants a stake on a piece of land.

Ecological and environmental issues

A variety of inter-connected and crippling ecological and environmental factors also come into play as policy issues. Only about 20 percent of Kenya's land is considered high potential. With the population growth rate of 4 percent per annum, land scarcity forces population migration to marginal areas where appropriate farming systems should be different from these hitherto known by the emigrants. It is in fact an unfortunate paradox that soil resources are seldom seen as vulnerable to mismanagement by those whose livelihood actually depends on them. Yet inappropriate farming practices, in condition with population pressures and natural phenomena such as drought are leading to a rapid reduction of the quality and quantity of arable land in some parts of Kenya, mostly through erosion. The government is currently intensifying re-afforestation programs and creating public awareness on the dangers of deforestation.

Agricultural Growth and Performance

Land Use Potential

Kenya is a land of striking topographical and climatical diversity ranging from the uninhabitable semi-deserts in the north and north west to the very fertile volcanic highlands found in the central and western parts of the country. A classification on land potential in Kenya was devised by Pratt, Greenway and Gwyne in 1966 on the basis of climate, soil, topography and vegetation types. Six broad ecological zones are distinguished in Table 3. About 18 percent of total land area constitutes as high and medium potential zones for growing coffee, tea, pyrethrum, cotton, maize, wheat, barley, groundnuts, pulses and oilseeds. Arid and semi-arid area covers 62 percent of total land area for subsistence farming and raising of livestock. In zone 6, rainfall is sparse and erratic. Livestock is kept by the nomadic pastoral people who inhabit this zone.

There are two rainy seasons in most parts of the country: the long rains from March to May and the short rains from October to December. On the highland there is a single rainy season approximately from March to September, whereas some areas to the west have fairly evenly distributed rainfall throughout the year. On the basis of annual rainfall, agricultural land is classified into three broad categories, namely, high potential, medium potential and low potential. Table 4 summarises these categories.

Table 3 Land Classification in Kenya by Eco-Climatic Zones

Zone	Current land use	Area ('000 hectares)	Percentage of total land area
1. Afro-alpine	Water catchment, tourism	80	0.1
2. High potential	Coffee, tea, pyrethrum cotton, livestock	5,300	9
3. Medium potential	Maize, wheat, barley, cotton, groundnuts, pulses, oilseeds, livestock	5,300	9
4. Semi-Arid	Subsistence crop farming, livestock sisal, wildlife	5,300	9
5. Arid	Wildlife and livestock	30,000	53
6. Very arid	Livestock	11,200	20
	Total	57,180	100

Source: Pratt, D.J., P.J. Greenway and M.D. Gwynne, "A Classification of East African Rangeland, with an Appendix on Terminology". *Journal of Applied Ecology*, No. 3, 1966.

Table 4 Categories of Agricultural Land in Kenya

Type of land	Hectares ('000)	Percentage of total
i High potential (Annual rainfall of 857.5 mm or more; over 980 mm, in the coast region)	6,785	13.04
ii Medium potential (Annual rainfall of 735-857.5 mm; 735-980 mm in the coast region and 612.5-857.5 mm in the eastern region)	3,157	6.06
iii Low potential (Annual rainfall of 612.5 mm or less)	42,105	80.90
Total	52,047	100

Source: Republic of Kenya, *Statistical Abstract*, Government Printer, Nairobi, 1984.

It is clear from the table that only about 19 percent of the total agricultural land receives annual rainfall above 612 mm which is suitable for growing a wide range of crops. The bulk of agricultural land, 81 percent, is of low potentiality and supports about 20 percent of Kenya's population and 50 percent of its livestock. This area requires to be developed extensively for improved farming and livestock production.

Production Structure

A dichotomy between small-scale and large-scale farms characterizes the production structure of Kenyan agriculture. The majority of the farming population are peasant farmers who produce mainly staple food crops for subsistence and very little surplus for marketing. On the other hand, there are commercial farms which are highly developed and produce both cash and food crops for local and export markets. Farms that are 8 hectares and above are defined as large-scale while small farms are less than 8 hectares. There are about 3,273 large and 1.5 million small-scale farms in the country.

The distribution of large farms by size of holdings is depicted in Table 5. The number of holdings between 0-19 hectares increased from 284 units during 1964-66 to 407 during 1969-71 and to 668 in 1983. Similarly, the number of holdings in the size-group of 20-99 hectares showed continuous increase from 518 during 1964-66 to 1125 units in 1983. On the other hand, the number of holdings declined in the size groups between 500-19999 hectares during the period. There are 10 to 15 farms of the size 20,000 hectares and above.

The relative importance of large and small farms can be seen in terms of gross marketed production in the country over a period of time (Table 6). The table shows a rise in the share of farm output marketed by smallholders from 40.7 percent in 1964 to 50.6 percent in 1974 and to 51.2 percent in 1983. The increase in the share of small farm marketed production has not been impressive during 1970s and 80s.

Agricultural Production

The performance of the agricultural sector is analysed both in terms of income generated in the sector and growth in production in physical quantity during the period 1964 to 1983. Table 7 shows the distribution of Gross Domestic Product at 1976 prices between agricultural and non-agricultural sectors and rates of growth in these sectors. It is evident from the table that the share of agriculture in income generation declined from 43 percent during 1964-66 to 38.5 percent in 1974-76 to 35 percent in 1983.

Table 5 Distribution of Large Farms by Size of Holdings (Average Number of Holdings)

Size of holdings in hectares	1964-66	1969-71	1974-76	1979-81	1983
9 – 19	284	407	451	634	668
20 – 99	518	623	626	879	1125
100 – 499	1048	1136	1241	1257	1276
500 – 3999	865	832	816	795	817
4000 – 19999	115	109	105	106	98
20,000 and over	13	14	13	15	10
Total	2843	3121	3252	3686	3994

Sources of primary data: Republic of Kenya, *Statistical Abstract*, 1972, 1976 and 1984, Government Printer, Nairobi.

Table 6 Gross Marketed Production from Large and Small Farms in K£ million (at current prices)

Year	Large farms	Small farms	Total	Percentage share of small farms
1964	35.8	24.6	60.4	40.7
1969	37.9	38.3	76.2	50.3
1974	73.4	75.0	148.4	50.6
1979	148.2	165.2	313.4	52.7
1983	271.3	284.1	555.4	51.2

Sources of primary data: Republic of Kenya, *Statistical Abstracts*, 1970, 1976, 1982 and 1984, Government Printer, Nairobi.

Table 7 Gross Domestic Product by Industry of Origin, Share and Rate of Growth: Averages 1964-66 to 1979-81

	K£ Million at 1976 prices			Percentage share of agriculture in total	Annual growth rate in percentage		
	Agriculture	Non-agriculture	Total		Agriculture	Non-agriculture	Total
1964-66	291.32	387.35	678.67	42.92			
					5.63	7.88	6.94
1969-71	383.05	566.00	949.05	40.36			
					4.54	6.17	5.52
1974-76	478.26	763.58	1241.84	38.51			
					3.71	6.11	5.21
1979-81	573.77	1027.10	1600.87	35.84			
1983	628.87	1171.89	1800.76	34.92			

Sources of primary data: Republic of Kenya, *Statistical Abstracts*, 1972, 1976, 1979, 1982, and 1984, Government Printer, Nairobi.

This is mainly because the income generated in non-agricultural sector grew faster (6.1 to 7.9 percent) than the agricultural income (3.7 to 5.6 percent per annum). The trend is consistent with the general hypothesis that the share of agriculture in economic activity declines during the process of economic development.

The trend in area, production and yield of major foodgrains during the period 1964-66 to 1983 is shown in Table 8. Maize which is the staple crop increased in production at the rate of 4.18 percent per annum during the period 1964-66 to 1979-81. Growth in productivity was higher (2.87%) in comparison to growth in area (1.23%) under the crop. This shows productivity contributed more to the increase in production than the area. Increase in productivity is mainly due to the use of hybrids and improved farming practices. Similar trend was also observed in wheat production. Growth in productivity was higher (2.16%) than the growth in area (0.42%) to contribute to the growth of production (2.57%). Wheat is mainly grown in large farms and the increase in area is marginal.

Table 8 Area, Production, Yield and their Rates of Growth of Selected Crops: Averages 1964-66 to 1979-81.

Crops	1964-66	1969-71	1974-76	1979-81	1983	Annual growth rate in percentage 1964-66 to 1979-81
Maize						
Area ('000 Ha)	1033	1091	1250	1240	1720	1.23
Production ('000 mt)	1050	1442	1583	1030	2000	4.18
Yield (Mt/Ha)	1.02	1.32	1.27	1.56	1.16	2.87
Wheat						
Area ('000 Ha)	112	133	109	119	115	0.42
Production ('000 mt)	145	227	177	212	270	2.57
Yield (Mt/Ha)	1.29	1.71	1.62	1.78	2.35	2.16
Rice						
Area ('000 Ha)	3.3	5.3	6.7	8.7	9.0	6.58
Production ('000 mt)	9.7	18.3	22.7	25.3	18.0	6.63
Yield (Mt/Ha)	2.9	3.4	3.4	2.9	2.0	0.00
Pulses						
Area ('000 Ha)	603	602	620	550	570	−0.62
Production ('000 mt)	268	276	305	235	230	−0.89
Yield (Mt/Ha)	0.44	0.46	0.49	0.43	0.40	0.00

Sources of primary data: FAO, *Production Yearbooks*, various years, Rome.

Rice is grown in four irrigation schemes namely, Mwea, Ahero, Bunyala and West Kano, managed by the National Irrigation Board. The production of rice increased from 9.7 thousand metric tons during 1964-66 to 25.3 thousand metric tons during 1979-81 at the rate of 6.63 percent per annum. The increase in production is solely contributed by the increase in area (6.58%) as the productivity remains the same. Growth in production of pulses showed a declining trend (−0.89%) due to the decrease in area under cultivation and no increase in productivity.

The production trends of selected agricultural commodities in the country are depicted in Table 9. Sorghum/millets, Cassava and Potatoes registered a small increase in production of between 0.25 to 0.5 percent per annum during the period 1964-66 to 197981. A considerable increase in production was achieved in case of sugar (17.03%), tea (10.10%), milk (9.02%) and fats and oils (6.78%). Coffee, cotton and beef increased at the rate of 4-6 percent per annum during the period.

Agricultural Research

Agricultural research has received attention since the colonial period, although with bias towards solving problems of the already advantaged groups. The impact of the research has however, been evident for hybrid maize development, coffee, tea and other high valued cash crops. A widespread and diversified network has been established, built largely on the research institutions founded in the pre-independence period. With the rapid increase in population, people tend to migrate into semi-arid and

Table 9 Production and Growth Rates of Selected Agricultural Commodities: Averages 1964-66 to 1979-81.

Commodities	Thousand metric tons					Annual growth rate in percentage 1964-66 to 1979-81
	1964-66	1969-71	1974-76	1979-81	1983	
Sorghum/Millets	320.0	330.0	362.0	332.0	260.0	0.25
Cassava	600.0	620.0	713.3	635.0	660.0	0.37
Potatoes	646.7	666.3	839.3	695.0	615.0	0.48
Sugar	33.3	121.3	163.7	349.0	–	17.03
Fats and Oils	40.0	56.0	90.0	106.7	–	6.78
Cotton	12.6	16.0	15.6	29.0	25.8	5.73
Coffee	45.9	56.7	73.0	85.6	95.3	4.25
Tea	21.8	37.8	57.4	92.4	119.3	10.10
Beef	109.3	131.0	116.7	198.0	194.0	4.06
Milk	230.3	833.7	783.7	840.0	1300.0	9.02

Sources of primary data: FAO, *Production Yearbooks*, various years, Rome and Republic of Kenya, *Statistical Abstracts*, 1973, 1982 and 1984, Government Printer, Nairobi.

medium potential areas. Therefore, greater research effort needs to be directed towards solving problems of these difficult areas.

Research programs are undertaken by the government, parastatals, universities and the international research organizations based in Kenya. These research centres are expected to undertake research programs based on priorities for the country. The Kenya Agricultural Research Institute (KARI) was established in 1979 to coordinate the agricultural research activities in the country.

The total government expenditure on research should reflect the research effort of the government. The expenditure on research and development in all fields is shown in Table 10. The proportion of the research funds taken by agricultural research is also shown in the same table for the period between 1970 to 1980. The proportion declined from 99% in 1970 to 68% in 1980 despite the importance of the agricultural sector in the economy. The proportion of agricultural research funds to GDP for the same period also indicates that only up to 0.35% of GDP was spent in agricultural research annually. It must then be concluded that there has been underinvestment in agricultural research. The proportion of agricultural research to GDP needs to achieve the level of 1% if the research funding is to be commensurate with the contribution of the agricultural sector to the economy. Development heavily depends on technology being generated or adapted. The level of research funding will determine the rate at which the new technology is generated and made available to farms. The sessional paper number 1 of 1986 on Economic Management for renewed growth proposes that the level of funding should attain K£10 million in 1986. However, more funds should be made available if the research programs have to achieve the desired goals.

The allocation of resources to research however, should be set within the framework of national objectives and constraints as spelt out in the development plans. The earlier plans emphasised increased growth per se

Table 10 Total Agricultural Research Expenditure as a Percentage of National Expenditure on Research and Development and as a Percentage of GDP.

Year	GDP/K£m A	National Expenditure on Research (K£) B	Expenditure on Agric. Research C	C/A (%)	C/B (%)
1970	512.51	396,607	391,507	.08	99
1971	570.06	232,851	207,424	.04	89
1972	666.22	1,422,138	1,405,711	.21	99
1973	749.21	2,259,074	2,132,708	.28	94
1974	907.63	3,031,945	2,901,101	.32	96
1975	1057.22	3,287,108	2,931,955	.32	89
1976	1278.10	4,259,433	3,668,383	.29	86
1977	1640.65	8,279,410	5,726,292	.35	69
1978	1788.41	8,936,422	6,374,553	.36	71
1979	1974.97	9,509,032	7,010,677	.35	74
1980	2235.37	10,844,000	7,381,000	.33	68

Source: Muturi, S.N. *et al.* 1982.

while the current plans focus on poverty alleviation and utilization of domestic resources. The first three plans required research to be focused on crops such as maize, wheat, coffee, tea and pyrethrum. This enabled these crops to attain higher rates of growth due to varietal improvement, disease control and expansion in area. Food crops such as sorghum, millet and pulses were essentially ignored and apart from small area increases for some crops such as rice, there was no significant growth in production.

In terms of regional focus, there has been a shift of priority in favour of arid and semi-arid areas due to the emerging land scarcity and population growth. The fourth Development Plan of 1979/83 specifically calls for special research and development programs in order to develop a viable crop and livestock systems for the drier areas. To this end, the National Dryland Farming Research Project has been established at Katumani in Machakos District. The Coast Province has, on the other hand been identified as having potential for tree crop development and therefore intensified tree crop research should follow for the region.

Recognition has been given to the need to re-orient the research focus as the structure of farms change. In the past, most research were meant to benefit large scale farmers. However, the emerging structural changes have signalled the policy makers to facilitate undertaking of the kinds of research which would be more relevant to the needs of small farmers.

Kenya has made considerable strides in its agricultural research, especially in the field of maize improvement. However, there is need to intensify the research effort to include soil management and the ecology of hitherto neglected areas and development of drought-resistant or drought-escaping crops for particular areas which are too dry for the Katumani maize. There should be continued research on maize, pasture, fodder improvement and zero grazing; economic crops for irrigation schemes and the water management in these schemes. Research on farm mechanization also tends greater attention than hitherto. For instance research on the available machinery, designing prototypes of new machinery appropriate for various farming systems and the dissemination of the research findings needs streamlining. Programs of research which have attained successful results such as maize improvement need not relax. It is noteworthy that since early 70s no major breakthrough, on maize research has been forthcoming. Since intensification of land use will be the primary source of increased agricultural output, this should call for increased research efforts to generate the necessary technology.

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5 Status and Needs of National Dryland Agricultural Research and Development: A Tanzanian experience

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Introduction

One area of deep and on-going concern among many policy makers and agriculturalists is the rate at which places that used to receive ample rain are now turning into marginal rainfall areas. Areas that produced a lot of maize, for instance, are now areas for the production of drought tolerant crops. Livestock production has increased and attempts at destocking these areas have met with moderate success.

Man and animal have been migrating in search of good pasture land for animal grazing. Now in Tanzania, it is common to see the Wasukuma natives of Mwanza and Shinyanga region – in places as far South as Sumbawanga. Other pastoral tribes perform similar migratory exercises. This disturbing tendency can most likely be attributed to the changes in rainfall patterns, which result in changes in vegetation and human activities.

Soil and water conservation problems are becoming increasingly serious in many parts of Tanzania, especially in the arid and semi-arid areas, where much of the resulting environmental degradation is irreversible. This situation is compounded by lack of research on tillage and farming systems, which have been the major factors causing erosion.

Research in soil tillage and farming systems offers more promise for major improvements in soil and water management than research in any other soil area. In the drier areas the most limiting factor in crop production is the rate of water supply. Soil sillage has a major influence on water intake, storage and evaporation, and on the extraction of water from the soil by plant roots. Such research is required to quantify erosion rates accurately and to develop effective water and soil conservation programmes.

The Dry-lands of Tanzania

These cover most of central Tanzania and parts of southern Tanzania along the Ruvuma river to the coast. The areas are shown in Figure 1.

Ecological Constraints and Potentials of Dryland Areas in Tanzania

The basic farming system practised in the dryland areas of Tanzania is integrated crop and livestock production. In the drier areas of Tanzania, the farming system in practice involves burning all crop residues and leaving the field bare. Then the field is sown in hills, in most cases before the rains. After the rains and when the seeds have germinated cultivation starts. The purpose of doing this is to make use of most of the rain and cause little disturbance to the soil. Time of sowing is thus very critical in these areas.

The main crops grown in the region are sorghum, millets, pigeon peas,

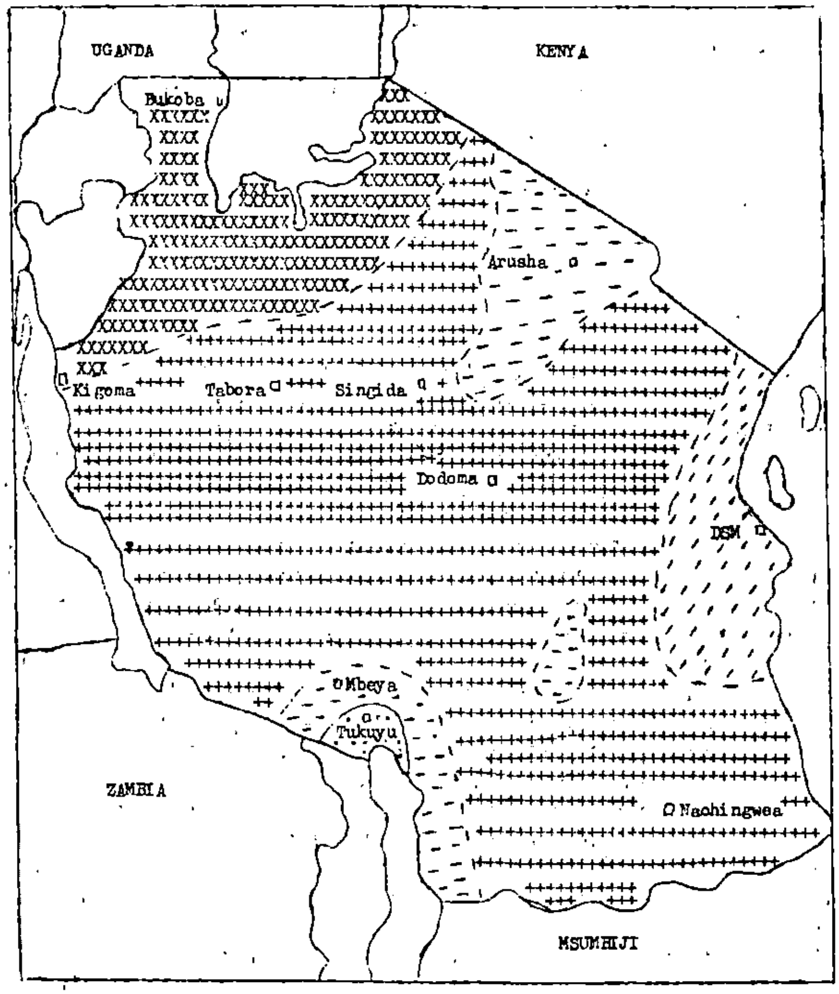

Figure 1 Broad-based classification of agro-climatic zones of Tanzania. (After George Philip and Son Limited, 1980 New Atlas for Tanzania Schools.)

Dryland savannah – prolonged drought and moderately hot.

Savannah – prolonged rainfall season and moderately hot.

Coast – all-year hot with bimodal rainfall pattern.

Highlands – high rainfall and moderately cold.

High rainfall and moderately cold.

cowpeas, cassava and sweet potatoes. Sorghum and millets have dramatically taken the areas that were formerly in maize production. Production of sorghum and millets in Tanzania has been steadily increasing from an estimated 3,000 tons in 1976/77 to an estimated 21,000 tons purchased by the National Milling Corporation in 1979/80 (Kasembe 1984). The increased production has been due to an increase in acreage rather than in productivity.

The predominant livestock in the dryland areas, and indeed in some other areas, are ruminants – cattle, goats and sheep. Most of these are indigenous breeds, well adapted to the climate and health stresses of the region.

Water is the major limiting natural factor for crop production in arid and semi arid regions. Rainfall is the only practical source of moisture available to most farmers. Unfortunately this is unpredictable and limited. Water harvesting techniques are not employed by farmers to conserve water for use during dry spells. It should be underscored however that there exists a potential for traditional smallholder irrigation in these dryland areas. As shown in Table 1, dryland areas under traditional smallholder irrigation cover approximately 15% of the partial and full scale irrigable land.

It is unfortunate however, that the advantages of irrigation farming in these areas have not been adequately realised. Poor planning of irrigation projects particularly the peasants' irrigation schemes is among the many problems that contributed to the lack of rapid progress of irrigation on a wide scale in Tanzania (Interim Report, 1982).

Another ecological constraint to the efficient use of rain water in these

Table 1 Area under traditional smallholder irrigation – 1980.

Region	Area – ha	Remarks
Arusha	13,347	
Coast/Dar es Salaam	53	
Dodoma	1,776	Dryland region
Iringa	828	
Kagera	5,983	
Kigoma	249	
Kilimanjaro	38,390	
Lindi	–	
Mara	–	
Mbeya	17,500	
Morogoro	2,212	
Mtwara	198	Dryland region
Mwanza	2,988	
Rukwa	500	
Ruvuma	14,580	
Shinyanga	14,184	Dryland region
Singida	267	Dryland region
Tanga	4,130	
Tabora	1,193	Dryland region
Total	120,378	

Note
A large portion of this irrigation practice is for the production of grape vines as is the case in Dodoma Region for instance and irrigated paddy as is done in Shinyanga, Singida and Tabora.

drought-prone areas is excessive run-off which consequently causes erosion. As the land lies bare and untilled, the rate of infiltration is considerably low. There is therefore a need to investigate and find ways of improving farmers' tillage and farming systems, with the resources available, aiming at water and soil conservation so that higher yields can be obtained with minimum inputs.

Status of Dryland Research in Tanzania

Tanzania inherited a lopsided agricultural policy from the colonial administration – a policy that was geared largely towards the production of export crops for use as raw materials in the industrialized countries (Interim Report, 1980). As a result, most of the research programmes were aimed at solving problems facing the plantation or estate farmers. Food production remained part and parcel of the subistence sector facing problems of weed infestation, bird attack, insects and diseases that seriously reduced the final yields realized by farmers.

The post-independence era in Tanzania saw a shift of emphasis in the strategy for agricultural development. The strategy was aimed at achieving self sufficiency in food production and at the same time, producing surpluses and packages of recommendations that were compatible with the farmers' levels of understanding, management, and resource base.

Research efforts in Tanzania under the aegis of the defunct East African Agriculture and Forestry Research Organization produced useful results that found immediate applicability in areas with more favourable rainfall. Since, however, the region covered by the Organization was quite extensive, the research findings in some cases tended to be less location-specific. In fact, agricultural research strategies for drought-prone areas were not clearly defined.

Production of drought-tolerant crops such as sorghum and millet has tended to be low partly because of ecological constraints and partly because the agronomic packages developed by research scientists were not compatible with the type of environment the peasant farmers were operating with. It became imperative therefore to develop agronomic practices which were relevant to the resource situation – both from the farmers' and environments' point of view.

Armed with this kind of policy direction, breeding objectives have been mainly directed towards developing early maturing genotypes that are drought tolerant and that have stable yields. These materials could also be grown during the short rains in those areas with bimodal rainfall pattern. A 90-day open-pollinated variety of maize locally known as 'Kito' has been released for production in the lowlands (0 to 900 m above sea level). Under optimum management it yields up to 4.5 tons/ha while under improved management it's yields range between 3.0 and 3.5 tons/ha. Under unimproved management practices, yields of 1.0 to 1.5 tons/ha can be realised. 'Kito' is an added release to the well accepted 'Katumani' variety developed in Kenya (Moshi, 1983).

Grain legume cultivars have also been developed with a wide range of adaptability. Two cowpea cultivars 'Tumaini' and 'Fahari' have recently been released. For both varieties, mean number of days taken to 50% first ripe pod stage ranges from 64 to 102 days depending on the location.

Yield levels realized under optimum management ranges between 1.8 and 2.2 tons/ha; under improved management, 1.5 tons/ha and under unimproved management practices, less than a ton/ha (Singh,1981).

Green-gram varieties with a growing season of 65 to 95 days have been released by the National Grain Legume Improvement Program. They yield from 2.0 to 2.5 tons/ha under optimum management, 1.3 to 1.5 tons/ha under improved management and less than 1 ton/ha under un-improved management practices (Patel, 1977; Mbowe and Price, 1982).

The National Roots and Tuber Improvement Program has similarly made commendable efforts and farmers in these drought-prone areas should now be growing high yielding cassava and sweet potato varieties with appreciable resistance to some of the common virus diseases.

The broad-based genetic diversity of sorghum has enabled it to be grown over a wide range of agro-ecological conditions. They range from low to high altitude areas. The aims of the sorghum and millet breeding program have been to develop cultivars with early maturing characteristics with a wide adaptability and stable yields. Tolerance to drought stress at various stages of the plants growth and to major pests and diseases also forms the backbone of the activities. Through the joint efforts of research scientists in Tanzania and EAAFRO, Sorghum and millet releases were made. Prominent among these were Serena and Lulu sorghum (tall and dwarf) and Serere 17 millet (Mushi, 1982).

Poor storability and palatability are some of the reasons that were responsible for the poor acceptance by farmers of the released sorghum varieties. Only recently has the sorghum program in Tanzania released a variety "Tegemeo" to add to the commercial Serena and Lulu varieties. This low rate of variety release can largely be ascribed to the lack of trained personnel – a problem that has prevailed for almost ten years since 1957.

The agronomic work for dryland areas has focused attention on the basic infrastructural variables such as climate, resource base and farmer characteristics. As a result of work done in this area, planting dates especially of sorghum and millets for the drought prone areas have been established. These times range between early December to early January in Tabora, late December to late January in Shinyanga, and late December to early January in Dodoma. Invariably these times are just before the rains or times when rains have started.

From sorghum and millet management trials which were run to determine combination of factors affecting grain yields, density levels and weeding regimes were established. For the dry-land areas, a plant density of 100,000 plants/ha 60 kg N/ha with a first weeding done 2 weeks after planting followed by a second weeding 6 weeks after planting should be the recommended package.

Current Research Strategy and Direction for Dryland Areas

Soil moisture or water conservation is the holding of enough water on an area of land to grow crops, if too much rain falls, and the holding of all or most of the rain on the land is inadequate (Jones, 1985). Since little rain is received in these areas the aim must be to allow all or as much as possible of the rainwater to enter the soil for future crop use.

Transferring of rainwater into the soil depends on two major factors: Rainfall intensity (mm/ha) and rate of infiltration (mm/hr). The ideal condition of transferring rainwater into the soil is when the rainfall intensity is less than or equal to the rate of infiltration, and the water holding capacity is equal to or more than the amount of rain falling. In practice, this ideal condition is never attained anywhere. The rainfall intensity is always higher than the rate of infiltration.

A tillage and cropping pattern is needed to provide a means of holding this high intensity rainwater much longer to give it time to infiltrate into the soil and minimise runoff.

The visual effects of soil erosion on arable land emphasises the seriousness of the problem. Water erosion is the most common type of erosion in these areas. Failure of rainwater to infiltrate into the soil causes much runoff which washes away fertile top soil as the water flows. With time, this causes the soil to be depleted of the essential macronutrients and organic matter as the water eats its way deeper into the soil horizons.

Research in several countries with dry farming areas has identified several tillage and farming systems for soil and water conservation. These range from zero, minimum or reduced tillage, ridging, strip and mulch farming. Intercropping of cereals with legumes is becoming increasingly important.

Currently, there are 4 on-station trials in the drier central Tanzania. Some are on-farm observations, begun this previous season, specifically for the weather conditions of the area.

Below is a project outline of the four experiments that were carried out at Hombolo in Dodoma region.

Project 1: Conservation tillage trial:

Objective:

To study the effectiveness of four conservation tillage methods on water and soil conservation.

Background:

Conservation tillage is a system of land and water use which aims at achieving sustained agricultural production while minimising the depletion of natural resources i.e. water, soil and soil fertility. It also minimises the use of high cost inputs. The appropriate type of tillage will vary from one region to another depending on rainfall reliability and soil characteristics. In all cases, the emphasis is put on the use of low cost energy conserving tools for minimum or no tillage and for land formations for water and soil conservation. Conservation farming as a whole involves a combination of tillage tools and cropping patterns in a way which enables the farmer to maximise production on a sustained basis through maximum utilization of locally available and naturally renewable resources.

Treatments:

i. Flat with no tillage: crop residue is burned, the field dry seeded in accordance to farmers practice.
ii. Flat with crop residue: Crop residue is spread in the field. Tillage is done immediately after the onset of rains and then seeded.
iii. Open ridges: These are made immediately after the onset of rains and then seeded on the ridge.
iv. Tied ridges: as in iii.

Trends:

Some visual differences were observed on the stand of cereals on the different tillage methods. Despite a dry spell which lasted for more than two weeks the flat with crop residue and tied ridges treatments seem to perform better than flat with no tillage and open ridges treatments.

Project 2: Sorghum/millet – *Crotalaria* intercrop:

Objective:

i. To study the effectiveness of Crotalaria – *Crotalaria ochroleuca* in improving soil fertility on an intercropped field.

ii. To investigate the effectiveness of Crotalaria in controlling weeds.

Background:

Although *Crotalaria* has been growing as a wild plant, in many parts of Tanzania, its potential as a crop in intercropping with food crops has not been adequately investigated. *Crotalaria* is known to fix larger amounts of nitrogen in the soil than any other legume. This means substantial fertility improvement without the use of chemical fertilizer. It is also reported that *Crotalaria* is very effective in suppressing weeds when intercropped. A final advantage of *Crotalaria* is that it provides forage for domestic animals This is advantageous to the farmer in Dodoma who regards cattle as equally important as his crops.

Trends:

The *Crotalaria* seems to be very sensitive to moisture for germination in the early stages of growth. Due to the weather conditions prevailing during the start of the season germination of *Crotalaria* was very poor and did not perform as expected. Good germination however was observed in plots where it was broadcast and raked after first weeding. With the continuing rains it remains to be seen if the *Crotalaria* won't be overshaded by the cereals which are already at an advanced stage.

Project 3: Farm Yard Manure Application Methods:

Objectives:

i. To study the optimum level of FYM application.

ii. To determine the best method of applying FYM.

iii. To relate the yield response to FYM to changes in the chemical and physical properties of the soil.

Background:

Use of FYM for soil improvement is common among farmers in the arid areas of Dodoma. The farmer's practice is to apply small amounts in heaps that are scattered throughout the field, or to broadcast. These methods do not appear to ensure that the amounts which are applied are adequate for proper plant nutrition. This experimennt investigates the optimum amount and method of FYM application.

Treatments:

Two rates were used 5 and 10 t/ha, spot applied, banded, incorporated and broadcasted.

Trends:

Clear visual differences were observed between the rates and methods of application. The high rate (10 t/ha) seems to perform better, and on the methods of application, spot application seems to do better in both rates, than other methods of application.

Project 4: Alley Cropping of Cereals with *Leucaena leucocephalia:*

Objectives:

To investigate different tree arrangements in order to achieve both high biomass production as well as improved crop yields.

Background:
Research on the possibility of intercropping tree legumes with cereal crops is gaining interest due to the multipurpose benefits which are gained. These include in situ mulch production for improving soil fertility, fodder for animals, and firewood for the farmer. It is necessary to determine the appropriate spatial arrangements of the trees in relation to the associated cereal crop for each agro-ecologic zone, because of the varying levels of competition which arise for moisture, nutrients and solar energy between the trees and the intercropped cereal crop. This is particularly important in semi-arid tropics where moisture and soil nutrients are the most limiting factors, to achieving high crop yields.

Trends:
This previous season, the cereals suffered severe moisture stress and withered, and had to be replanted. The replanted cereals are doing well, good stand and vigour. The experience with *Leucaena* was rather discouraging. There was very poor germination of *Leucaena* seeds, and compounded by drought, seedlings withered away. Replanting of *Leucaena* seeds was done but this too was attended by very poor germination. It would seem therefore that *Leucaena* seeds will not germinate well under such weather conditions. Planting seedlings immediately after the onset of rains, as observed at two locations (schools), seems to be more encouraging. Seedlings at these locations took up very well and there should be some data on this project next season.

Land Conservation Project in Dodoma Region, HADO

Besides research activities in Dodoma region, national land conservation project known as HADO (Hifadhi Ardhi Dodoma) has been going on since 1973. The project is headquartered in Kondoa District, and has branches in Dodoma and Mpwapwa Districts. The project is sponsored by SIDA.

Phase I of the project, embarked on soil and water conservation activities on uncultivated land in Konda District where the problem was very severe. The activities included:

- planting of fast growing trees (foreign)
- Planting and seeding of local species of grass seed on bare land.
- Building of bands along the contour, on slopes and planting of species of *Agave* and *Dodonea visicosa* to hold on the soil.
- Building of bands; planting of trees and elephant grass on river banks and river beds to minimize river bank erosion.
- Building of bands and check dams, and planting these with trees, grass and sisal, to control gully erosion.
- Tied ridges also have been used to control sheet and rill erosion.
- Destocking of about 80,000 livestock concentrated in an area of 1625 km^2 from upper slopes of Kondoa Irangi to the lower slopes in 1979 contributed greatly to the success of the project in Kondoa District.

Phase II of the project starting 1985/86 will concentrate on Farmland conservation in Dodoma and Mpwapwa Districts. The activities will include:

- The building of cut-off drains on farm headlands for soil and water conservation on slopes.
- The use of contour bands along the farms and planting of *Panicum*

macaricariensis and *Leucaena glauca* trees for soil conservation and soil fertility improvement. Destocking will also be affected on the most severely effected areas immediately on the onset of rains so that natural grass and other vegetation could be established during the rainy season.

Seminars will also be conducted in the villages, on the importance of soil and water conservation, so that villagers can participate fully in these conservation activities in their own farms, when HADO teams visit their villages.

Needs of a National Dry-land Agricultural Research Programme

In the preceding paragraphs, mention was made of the type of potentials and limitations of drought prone areas of Tanzania. In order to develop and implement a viable and integrated agricultural research programme, emphasis must be placed on system description and diagnosis.

A comprehensive understanding of farming practices, problems and opportunities faced by farmers must be achieved. It has been the case in many instances, to transplant a package of recommendations to a community without the necessary adaptive modifications. A simultaneous institution of the often necessary supportive infrastructure has been lacking and the needs of the recipient farming community or its social values have been largely neglected. The identification of farmers' problems and their feasible solutions, social values, resource base etc requires involving farmers to a greater extent as partners in the research process.

Agricultural production in most developing countries is in the hands of the rural poor, who generally practise traditional agriculture (Mitawa, 1984). In the dry-lands of Tanzania, these limited resource farmers grow crops and keep livestock, and depend heavily on family labour for agricultural production. The research strategy for these areas therefore must be characterised by an element of low-cost. If should be a programme that would design and develop appropriate technology that could be introduced to the community with a minimum of disruption to the traditional systems.

A considerable amount of work on dryland farming has been done. There is a basic understanding of the causes of soil erosion and how to reduce it. Similarly there is a growing body of knowledge on agronomic variables that could be formulated into a package of recommendations for the dry land areas. Experience elsewhere has shown that ratoon cropping could be a suggested practice in the dryland areas. In Tanzania, and indeed in other dryland regions where livestock form an integral part of the agricultural enterprise, this practice would achieve very limited success because of the livestock. However the ratoon crop could still be taken after the normal harvest for the preparation of silage.

Dry-planting is widely practised in Tanzania where rainfall is marginal. Despite its wide adoption, the practice has its inherent problems in that it requires farmers to use a higher seed rate for their cereals. This is necessary in order to cater for some that will be lost to insect pests and some that will die from lack of moisture.

The success of efforts to increase productivity will depend on the success with which the new innovations and the appropriate supportive infrastructure can be integrated with systems of traditional agriculture in which the small farmer predominates (Mitawa, 1984). There should inevitably be a growing concern toward broadening the base of participation by the farmer.

This invariably leads one to consider the farming systems research as a strategy for development.

Summary

In dryland areas, conservation of soil and moisture is essential for maintaining and increasing food production. Tanzania experience shows that these areas are fairly fertile and availability of animal manure is not limiting. The most limiting factor is rainfall which in most areas is less than 700 mm and is distributed over a relatively short period of time.

This paper reflects on some basic components of research work done in Tanzania, with respect to crop production. The primary emphasis has been to develop early maturing crop varieties suited for these environments. Commodity research scientists in the National food crop research programs have bred and developed cereal and grain legume varieties that match well with the rainfall regime of the dryland areas of Tanzania. Certified seed of Maize, Sorghum and Millets, Cowpeas and Greengram is being produced commercially for distribution to farmers. Other agronomic practices suited for these areas are also discussed.

A description of dryland areas is presented and the ecological constraints and potentials for crop production in these places are described. The basic farming system in these areas is that of integrated crop and livestock production. Because of large numbers of animals kept, soil erosion is rampant. Torential rain that falls at times has been known to aggravate the situation. Tree felling for firewood and other domestic activities has rendered most of these areas devoid of natural forests. Vast areas are now characterised by thorny shrubs and thickets.

Alternate soil surface and moisture management strategies are discussed with particular reference to small-scale farms. National aforestation programs have been carried out and now places like Kondoa don beautiful forests. Other areas of site-specific research include merits of dry planting, ratoon cropping, pre-germination and population studies.

Basic considerations for research and development are presented. Foremost among these are a comprehensive understanding of farming practices and a knowledge of the economic and social situation and needs of the clientele group.

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PART II

Crop Production

6 Breeding Sorghum for Drought Resistance

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Abstract Recent research on field screening sorghum under severe drought stress has led to important developments in the understanding of drought tolerance and to improved field screening techniques. Two distinctly different types of stress response have been identified and are directly related to the stage of growth when stress occurs. One type (pre-flowering) is expressed when plants are stressed prior to flowering during head development, while the other (post flowering) is expressed when severe moisture stress occurs during the grain filling stage. Plant symptoms indicating either a desirable or undesirable reaction to these two types of stress can be visually rated in field nurseries. Excellent sources of tolerance to each type of stress have been identified. Many lines which possess a high level of tolerance at one stage tend to be susceptible at the other stage. However, some do possess good levels of tolerance at both stages. Efforts are underway to combine the two types of tolerance into the same line or the same hybrid. The use of multi-location field screening nurseries with different degrees and types of stress is suggested as an effective drought screening and breeding technique. Close attention should be given to the stage of growth when stress occurs. Collaborative research among researchers in drought prone areas of the world which includes extensive germplasm and information exchange is encouraged and should be very useful in developing sorghums with enhanced drought tolerance.

Introduction

Drought stress is a universal constraint to sorghum production worldwide. Most of the sorghum growing area of Africa is drought prone. Therefore, adequate production under drought stress is essential. Improved drought tolerance through breeding would be a major contribution to increasing or stabilizing production of sorghum.

Development of sorghum with improved drought tolerance has recently received increased emphasis in the USA and internationally. Only in recent years have large sorghum breeding and screening nurseries been devoted specifically to selection for improved drought tolerance. Recent emphasis on field screening under severe drought stress has led to significant developments in our understanding of drought tolerance in sorghum. Some selection and screening techniques and concepts have been developed which I believe are useful internationally in breeding for improved drought tolerance. In this paper, I will discuss some of the breeding and screening techniques we use and their application to Africa.

Concepts

Three important growth stages are recognized in sorghum as they relate to drought stress:

(1) the seedling establishment – early vegetative stage;
(2) the pre-flowering stage (head differentiation to flowering);
(3) the post flowering stage (grain development)

Recent sorghum research in Texas and other locations has placed an increased emphasis on understanding drought response. We have identified two distinct types of stress responses in sorghum which are related to stage of growth when stress occurs. The "pre-flowering" or "early season" response occurs when plants are under significant moisture stress prior to flowering.

Specifically, this growth period is from panicle differentiation, or very shortly thereafter, until flowering. The other distinct response, called "post-flowering" or "late season", occurs when plants are under severe moisture stress during the grain filling stage, and especially during the latter portion of grain fill.

Plant symptoms indicating either a desirable or undesirable reaction to these two types of stress can be visually rated in the field. Symptoms of pre-flowering drought stress susceptibility include: leaf rolling; uncharacteristic leaf erectness; leaf bleaching; leaf tip and margin burn; delayed flowering; "saddle effect" – only end plants next to alleyways produce a panicle; poor panicle exsertion; panicle blasting and floret abortion; and reduced panicle size. Tolerance to pre-flowering drought stress is indicated by the alternative condition in each instance.

Symptoms of post-flowering drought stress susceptibility include premature plant (leaf and stem) death or plant senescence, stalk collapse and lodging, stalk rot (charcoal rot, *Macrophomina phaseolina*), and sometimes a significant reduction in seed size, particularly at the base of the panicle. Tolerance is indicated when plants remain green and fill grain normally. Such green stalks are resistant to charcoal rot and stalk lodging. The cultivars are referred to as having good "stay-green" or as "non-senescing". The post-flowering response is most obvious and distinct in plants which have been grown under favorable soil moisture and growth conditions until

Table 1 Pre- and post-flowering drought tolerant sorghums

Pre-flowering tolerant	Post-flowering tolerant
Tx7078	B35 (SC35-6sel) (IS12555 deriv)
Tx7000 (Caprock)	SC35-14 (IS12555C)
BTx623 (BTx3197xSC170-6)	SC33-14 (IS12553C)
Tx430 (Tx2536xSC170-6)	SC56-14 (IS12568C)
Tx2536	SC599-6 (R9188) Rio deriv.)
Tx2737	2790E (SC56xSC33)
Early Hegari	1778 (SC56xSC33)
P954035	NSA 440
RS610 (Hybrid)	BKS9
Hageen Durra 1 (Hybrid)	KS19
SC701-14 (IS3462C)	P898012
BTx3197 (C.Kafir-60)	P954035
SC414-12E (IS2508 deriv)	SC23-14 (IS12543C)
TnGbResW	SC38-14 (IS12558C)
Tx432 (SC599-6xSC110-9)	SC328-14 (IS8263C)

flowering, with a severe water deficit developing during the late stage of grain fill. When water stress develops gradually and occurs over the entire season, these distinct stress responses may not be as obvious. Sometimes there is a blending of the two types of stress response.

High yielding genotypes with a large grain sink size relative to the vegetative portion of the plant are more susceptible to post-flowering drought stress than are low grain producing genotypes. Susceptibility to charcoal rot is predisposed by severe water stress during the latter stages of grain fill. Because of this strong relationship, charcoal rot is treated primarily as a post-flowering drought stress problem. Rather than inoculating stalks with charcoal rot infested toothpicks, genotypes are rated for presence or absence of premature leaf and plant death when they are under water stress at or near maturity.

Excellent sources of tolerance to each (pre and post flowering) type of stress have been identified (Table 1). High levels of both type of tolerance are generally not found in the same genotype. However, some genotypes possess moderate to good tolerance to both types.

Breeding and Screening Techniques

The association of major physiological and morphological traits with drought tolerance has been studied by several workers. Technology exists for the evaluation of such traits but breeders have made little use of the techniques to select for improved drought tolerance in sorghum. It appears that individual physiological traits identified to date are not sufficiently related to drought response to merit selection based on that trait.

Significant variability exists in the drought response of different sorghum genotypes. A number of breeding and screening techniques have been tried or proposed for sorghum. Several of these involved screening for certain physiological or morphological traits using laboratory or field screening methods, in combination with selection of other desirable plant and grain traits, but little if any progress has been documented. Until very recently, only limited breeding effort has been placed on drought tolerance as a primary breeding objective. In most cases, selection is first practiced for yield, adaptation, and disease or insect resistance. This is often done under favorable moisture conditions, with only the surviving advanced generation genotypes finally evaluated for drought tolerance or adaptation under severe drought stress.

Many sorghum breeders believe that breeding progress is most rapid when early generation selection is done under optimum or near optimum conditions which allows reliable expression of yield potential. This concept is supported by studies in other crops on heritability of yield and rate of genetic advance. In the case of drought tolerance, extreme variability in timing and amount of rainfall, along with variability in soil type, depth, fertility, pH, and water content contribute to a strong genotype X year or genotype X location interaction especially under low rainfall conditions. The present knowledge of distinctly different reactions to drought stress at different growth stages explains much of the lack of progress in the past in selecting sorghum under dryland, low rainfall conditions.

Our approach to breeding for drought tolerance is to practice early generation selection under naturally occuring dryland, low-rainfall conditions. Duplicate nurseries are evaluated under irrigation where yield potential is expressed. Large amounts of diverse germplasm are evaluated in field screening nurseries at several locations having different stress environments, different planting dates, and different water regimes. This approach helps to insure stress at different stages of growth.

Selected progeny from the field nurseries are further evaluated under rainout shelters and a line-source irrigation gradient system. Regulation of moisture stress at different growth stages is essential for significant progress in breeding for drought tolerance.

At the pre-flowering screening nurseries, the combination of sandy soil and high summer temperatures create drought stress during the pre-flowering stage. The Chillicothe, Texas location, with extreme heat and low rainfall during midsummer, consistently produces severe pre-flowering stress, especially in plantings made in mid or late June.

In the post-flowering screening nurseries, irrigation is applied during the early growth stages to produce good growth and yield expression. Irrigation is terminated prior to anthesis which allows moisture stress to develop beginning near the flowering stage, and intensifying during grain fill.

In nurseries where post-flowering drought tolerance is evaluated, each entry or plot is subjectively rated for the amount of premature leaf and plant death. Ratings are made on a 1 to 5 scale where 1 = completely green, to 5 = dead. Ratings are normally made at or soon after physiological maturity, but can be made anytime that differences among genotypes appear. Percentage of plant lodged due to stress is also taken. In West Texas, the nursery is often left standing for an extended period following maturity to allow stalk lodging to occur. This facilitates the identification of entries which have stalks weakened by water stress. It also allows for selection of genotypes with anatomical stalk strength traits. Knowledge of maturity is critical because sorghum has a period just prior to physiological maturity when it is most susceptible to post-flowering stress. Plants a few days earlier or later in maturity may show little premature senescence. Therefore, flowering notes are taken on all plots and comparisons are made only among entries of similar maturities.

In nurseries where severe water deficits occur prior to flowering during the panicle development stage, subjective ratings can be recorded whenever distinct differences in drought response appear. Rating is done on a 1-5 scale where 1 = excellent and 5 = very poor response. Prior to heading, ratings can be made on leaf stress symptoms indicating drought susceptibility such as rolling, excessive erectness, bleaching, and firing. Ratings can be made on each trait separately, but are often combined into a single overall drought susceptibility rating. Leaf rolling is normally the first visible symptom of drought stress. Excessive leaf erectness usually follows. Some cultivars have erect leaves in the absence of stress, so care must be used when evaluating this trait. The leaf angle of the lower leaves generally indicates whether or not a cultivar has genetically controlled erect leaves. Leaf bleaching refers to a loss in green color during the hottest portion of the day, causing a bleached effect. Care must also be used when scoring this trait because there is a range from dark to light green leaf color among different genotypes even in the absence of stress. Leaf margin and tip burn is usually the last vegetative drought response to appear. Scoring on the early vegetative response is most efficient when done within related germplasm. Widely diverse material may give rather different appearing responses, with a poorer relationship of vegetative symptoms to eventual performance. Some cultivars are very susceptible to another kind of leaf necrosis called leaf firing, where large sections of the leaf die rapidly and usually at about flowering time. This type of leaf firing is different from the leaf margin and tip burn described previously and does not appear to correlate well with final yield. Drought induced leaf necrosis is characterized by the absence of anthocyanin pigment and is thus distinctively different from coloration due to other causes, such as disease or insect injury. Later appearing symptoms caused by moisture stress prior to flowering include delay in flowering, panicle and floret blasting, poor panicle exsertion, reduced panicle size, and the "saddle" effect. These symptoms can be rated individually or in combination. Delay in flowering is evaluated by comparison with non-stressed plantings. These late-appearing symptoms are the best evaluation of pre-flowering drought tolerance. Such ratings may be made at or after maturity. Evaluation of pre-flowering drought tolerance in very early maturing genotypes is difficult because they often escape water stress.

In field screening nurseries, standard checks are used every five or ten plots. Alternating every fifth plot with a pre-flowering tolerant (post-flowering susceptible) line such as Tx7078 or Tx7000 and a post-flowering tolerant (pre-flowering susceptible) line like B35-6 provides a reference for comparison. By comparing ratings with those of the adjacent checks, adjustment for variability within the field can be made. Whenever possible, we furrow-dike between beds in our dryland nurseries to encourage uniform water penetration and soil moisture. The furrow-dikes are maintained throughout the entire year to as uniform a soil moisture profile as possible. Short (5-6 m), single row plots are used in most screening nurseries. Only advanced material is replicated. Multiple row plots are used only for special studies.

In addition to field screening, a sprinkler irrigation gradient system is used in the dry environment of West Texas to manipulate timing and quantity of water applied. The advantage is two fold: (a) the evaluation of plant response to a wide range of stress under otherwise identical conditions; and (b) manipulation of onset, cessation, and degree of stress. In these evaluations, it is important to recognize the different drought stress responses before interpreting results from the gradient system.

Disadvantages of the system are the influence of wind on water distribution and the inability to control precipitation. The amount and frequency of irrigation may be less than ideal. However, reaction under the system in West Texas correlates well with our field evaluation.

The use of gradients may be of only limited value in areas where rainfall is high during the main part of the regular crop season. Use of gradients during the dry off season is not recommended due to different yield responses, especially with photosensitive or partially photosensitive sorghums which are greatly affected by different day lengths.

Rainout shelters are also used to supplement evaluations made in field nurseries. Untimely rains often prevent evaluation or restrict evaluations to short periods during the growing season. Rainout shelters can be used to greatly accelerate and improve the efficiency of selection by controlling both timing and amount of water applied, while otherwise maintaining a near-normal environment. Pre and post-flowering stress ratings under shelters in Texas have corresponded well with known field reactions. Single-row plots of 400 breeding selections can be evaluated for the pre-flowering drought stress in one 40 ft × 60 ft (about 12 m × 18 m) shelter.

In Sudan, drought screening nurseries similar in many respects to those used in West Texas have been successfully used in breeding for drought resistance. Breeding material is screened in large field screening nurseries and subjectively rated. One nursery is under sandy soil, low (350 mm or less) rainfall, and stress prior to flowering is usually severe. The other is under heavy soil and higher rainfall, but stress often becomes very severe late in the season during grain fill.

Drought tolerant lines selected in Sudan and Texas perform very much as expected at the other location. Pre-flowering tolerant lines developed in Texas perform very well on the pre-stress location (El Obeid) in Sudan, while post-flowering tolerant lines identified in Texas also possess very good "stay green" under heavy soil (Gadambalia and Wad Medani) in Sudan. Although there is less information in this regard in West Africa, observations in 1986 indicate that several drought tolerant sorghums identified as drought tolerant in Sudan and Texas show excellent drought tolerance in Niger. Limited observations in Mali also indicated similar results.

The extreme importance of drought tolerance in the seedling establishment – early vegetative stage in much of Africa is recognized. More information is needed on drought tolerance at this stage, including seed, rooting, etc. effects, and the relationship of seedling drought tolerance to that at more advanced growth stages.

Summary and Conclusions

1. The empirical approach, utilizing large field screening and breeding nurseries, subjective scoring, and the principles described in this paper, is a drought screening technique that has proven successful.
2. Utilization should be made whenever possible of the local environment in the regular growing season. It is important to be familiar with the normal rainfall pattern, soil type, soil problems, and with other major constraints to growth and production, so that the effect of moisture stress will not be confused with or confounded with problems caused by other biotic or abiotic factors.
3. Be familiar with and be able to recognize the various drought responses of sorghum at the three major stages of growth.
4. Know the stage of growth when stress occurs in each nursery, by recording flowering date, rainfall data, etc. . . and make selections and interpretations accordingly.
5. Distinguish between drought tolerance and other aspects of adaption that affect growth and performance. When screening for drought tolerance, other serious constraints such as soil problems or soil variability should be removed, if possible, or at least minimized.
6. For drought tolerance screening, the following is encouraged: use multi-locations with differing stress, diverse germplasm, quick visual ratings, screening in early as well as in advanced generations, exchange of drought tolerant germplasm among sorghum workers, and constant exchange of information. Extensive yield testing is not the best use of time and resources, and visual ratings are sufficient until final evaluations.
7. There is a need for a better understanding of mechanisms of drought resistance as well as on the nature and inheritance of resistance. Such basic studies are encouraged and should contribute to the development of more rapid and efficient screening techniques.
8. The excellent drought tolerance, yield stability, and other adaption traits found in many local cultivars in Africa should be utilized extensively in African drought breeding programs. These stable producers can be converted in photoperiod insensitive types and their grain to stover ratios

changed. Intercrosses of such converted lines can be made in temperate zones with elite, high yielding sorghums. Such materials can then be returned to the host countries for on-site selection and utilization.

9. Collaborative research programs on drought tolerance can be of great mutual benefit to both the U.S. and African programs.

7 Genetic and Environmental Considerations in the Improvement of Drought Stress Avoidance in Sorghum

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Abstract A review is given of the essential and practical possible solutions to breeding sorghum for drought stress avoidance, in terms of drought escape and dehydration avoidance. The possible associations between the physiological components of stress avoidance and plant production are discussed. The role of root growth, leaf area, epicuticular wax and osmotic adjustment under stress are considered and some guidelines for selection criteria in sorghum are proposed.

Introduction

Breeding sorghum for stable productivity under conditions of drought stress is a special case in the general problem of crop plant breeding for drought resistance. It permits drawing upon information developed for other grain crops. Sorghum is different only to the extent that some mechanisms of drought resistance may be relatively more or less important than in other crops and genetic variation exists for some mechanisms, opening the way for genetic improvement. For a wider and more comprehensive discussion of the problem of drought stress and resistance in crop plants the reader is referred to several recent reviews on the subject.

Plant breeding for drought resistance merges two different disciplines, namely, plant genetics and plant physiology. Most problems encountered by plant breeders or by physiologists who attempt to contribute to the improvement of drought resistance of crop plants lie at the interface of the two. For the breeder, the main problem is that a routine methodology has not been developed, at least not to the extent that a breeder with no understanding of the major physiological processes involved in plant water relations can successfully perform selection. On the other hand, plant physiologists often do not understand that in logistic terms plant breeding is an industrial endeavour, where raw genetic materials are processed along established "production lines" towards the release of a competitive and cost-efficient "product". Thus, what they may feel is a potential selection method could be useless if it does not fit within the logistics of the program, in terms of speed, cost and available technology.

This review will attempt to crystalize the most important and practical contributions of both plant breeding and plant physiology towards practical solutions in the genetic improvement of sorghum performance under drought stress. The detailed theoretical considerations and an expanded discussion of the physiological background may be found in several of the cited references. Since in this area the unknown is greater than the known, some assumptions will be made and speculations offered – in order to promote further thinking and experimentation on the subject.

Plant productivity and drought resistance

For any genetic attribute to be introduced into a well-yielding genotype, linkage or physiological compatibility between the trait and the complex control of yield potential should be considered. This is of special importance for the subject matter considered here, since some traditional views assume a linkage between drought resistance and low yield potential.

The yield performance of a genotype in any environment is primarily conditioned by what constitutes the complex genetic control of yield and by the optimization of its phenology with respect to the thermal and photoperiodic environment. Drought stress would reduce yield from the potential set in the given genotype. However, many reports for various crops show that irrespective of the plant's physiological response to water stress, yield under stress will tend to be higher in a genotype of a higher potential yield. High yielding genotypes may present poor stability under changing water regimes but absolute yields under stress may still be relatively high. A genetic background of a high yield potential is conducive to yield performance under stress, irrespective of drought resistance. It therefore emerges that breeding for drought resistance should be built upon a genetically high yield potential. The incorporation of some drought resistance into a potentially high yielding genotype would take advantage of its yield potential under stress and improve its stability of performance. Conversely, the recovery of physiologically drought resistant materials from a poorly adapted and low yielding germplasm is no serious solution, unless such materials are used in crosses to improve their potential yield.

The merging of physiological drought resistance attributes and high yield potential raises the question whether the two are physiologically compatible. A complete answer is yet unavailable, but some assumptions can be made, as based on the little information reported. For example, extensive root growth, which is an important drought avoidance attribute in some environments, must be achieved at the expense of the given and finite amount of dry matter produced by a crop and at least theoretically dry matter invested in roots is taken off the investment in other plant parts, including economic yield. Osmotic adjustment, although undefined yet in quantitative terms of energy requirements, may pose a "cost" to the plant. However, it must be considered that when a high yielding and drought resistant genotype is designated to be grown *primarily* under drought stress conditions, reductions from the potential yield due to investments in buffering against the effect of stress is irrelevant – because potential yield will never be materialized in such an environment. A tradeoff likely exists between some investments of energy in drought resistance and the potential yield. For genotypes designed for a stress target area, there is no *a priori* conflict between drought resistance and actual yield, in spite of a suspected negative association between drought resistance and potential yield. Such varieties would constitute of what often has been found as very stable varieties of moderate yield potential. On the other hand, it is unlikely to expect that a variety can be adapted to the full spectrum of conditions, ranging from severe stress to potential environments. The ability to define the target (stress) environment and to be able to direct the breeding program towards that environment is therefore a primary step in designing a selection program.

Undoubtedly, some traits that confer drought resistance or xerophytism may indeed contrast plant productivity. Such traits would be of little use, if not harmful, in the context of maximizing yield under stress. One prominent example is the sensitive closure of somata (at relatively high turgor potential) upon leaf dehydration. This mechanism is common in xerophytic natural vegetation. It would ascribe an evolutionary advantage to the population, as it should ensure the production of at least one seed every year. However, fitness in the evolutionary sense does not comensurate with crop plant productivity under stress, where gas exchange must proceed while making efficient use of all available water. This is based on the strong and well-established association between crop yield and transpiration. The sensitive closure of stomata was found to be an important trait in ascribing drought resistance to the primitive "Latente" race of maize, as possibly mediated by high abscisic acid production under stress. This is perhaps the reason why maize breeders found it difficult to introgress the "Latente" type of resistance into high yielding materials. Undoubtedly, the selection for high yield results in a correlated increase in stomatal conductance. An effective drought resistance mechanism in the domain of crop plants must support the continuation of leaf gas exchange under stress. The selection for drought resistance within a potentially high yielding germplasm would very likely provide the desirable result, in this respect.

The practical significance of several drought resistance mechanisms in sorghum

Various possible mechanisms of drought resistance were investigated in sorghum, including drought escape, dehydration avoidance and dehydration tolerance. For a number of recognized drought resistance mechanisms, the available information is insufficient for their application to selection work, either because of methodological problems or because of a lack of understanding how and if they are related to plant productivity under stress. This review will therefore deal only with those mechanisms for which the available information allows a reasonable level of confidence with respect to their use in breeding.

Drought escape

Although drought escape does not essentially involve any interaction with the stress environment in the narrow sense, it is a practical and important attribute. Drought escape creates a dis-synchronization between plant development and the occurence of stress, primarily by a short growth duration. It is therefore effective when stress becomes important during the latter stages of growth, causing plants to escape a late-season stress. It is most effective when sorghum is grown largely on stored soil moisture, with little seasonal rainfall. The duration of growth can then be optimized by an exact fit to the available moisture at planting and even to plant density (Blum 1970). However, when late-season rainfall is expected to induce recovery after stress, late flowering genotypes offer a better option for recovering yield by renewed growth from tiller buds. The option for recovery in late genotypes is practical only as long as recovery is not too late and outside the effective season (in terms of temperatures, diseases, insect infestation etc.). For example, it is quite common in several sorghum growing regions that the new (and late) regrowth after stress is totally destroyed by stem borers or by the sorghum shoot fly (*Atherigona varia*). In such environments, insect resistance becomes an integral part of the genotype's ability for a successful recovery after stress.

Although drought escape does not appear to involve any specific reaction to water stress, this is not totally true. Early maturing genotypes do not only use less water due to their shorter growth duration, but they use less water at most growth stages, because of their smaller leaf area (Blum 1970, Blum and Arkin 1985). Secondly, partly because of their smaller leaf area, early maturing genotypes are characterized by a greater ratio of root length density (cm root/cm^3 of soil) to leaf area (cm^2). This would be translated into a better leaf water status under conditions of high evaporative demand or soil moisture stress (Blum and Arkin 1985), as compared with later genotypes, at the same date. Early sorghum genotypes are well known for their lower yield potential. The preceeding discussion on the tradeoff between drought adaptation and potential yield is quite relevant here.

Drought Avoidance

Sorghum genotypes (as the case is also for wheat, millet, rice, maize, and soybeans) differ in their leaf water potential under conditions of moisture stress. Drought avoidant genotypes maintain a relatively higher leaf water potential. Several reasons are possible for maintaining a higher leaf water potential in drought avoidant genotypes.

Root growth and development is a key feature. Where soil characteristics offer a greater resistance to root growth and expansion and where moisture is available at deeper soil layers, root growth attributes are detrimental for maintaining dehydration avoidance. Simulations performed by the SORGF sorghum model predicted a significant contribution to yield under stress from a promoted root growth in heavy soils of relatively high bulk density (Jordan *et al* 1983). Variations in root growth rates, root branching and root depth were already revealed in sorghum (Jordan and Miller 1980) and hybrids appear to excell open-pollinated varieties in this respect (Blum *et al* 1977). It must be realized, however, that the environmental influence on root growth and pattern is very strong. Firstly, the ranking of genotypes for their root growth attributes may differ with soil type and its moisture content. This was found in rice (Ghildyal and Tomar 1982) and wheat and it may likely occur also in sorghum. Secondly, a specific strong effect on sorghum root distribution in the soil is exercised by the pattern of rainfall (or irrigation) and the resulting soil surface wetting and drying cycle. By maintaining the soil surface wet, a high rainfall frequency promotes the production of new adventitious roots from the plant's crown, at the expense of growth and penetration of existing roots. On the other hand, when the soil surface remains dry, the development of new crown roots is inhibited and existing roots grow and penetrate into deeper soil horizons (Blum and Arkin 1985, Blum and Rachie 1984). Root observations and measurements as a screening technique for dehydration avoidance are therefore impractical, because of the need for a relevant and a standardized soil environment and because of the amount of labor involved. It is far simpler to measure the end-result in terms of canopy water status, as will be discussed below.

Dehydration avoidance results also from an efficient control over transpiration. Such a control must not be achieved by way of sensitive stomatal closure, for reasons already discussed. The development of high cuticular resistance not only contributes to the water economy of the plant but it improves the control of stomata over the leaf water status, as no alternative pathways of water loss are open. A high cuticular resistance in sorghum is largely achieved by a higher rate of epicuticular wax load (Blum 1975, Jordan et al 1984). While epicuticular wax load is largely controlled by a single genetic factor (*Bm*), additional minor factors affect its inheritance Epicuticular wax load is also influenced by the environment (Jordan *et al* 1983). Conditions of drought and heat stress as well as high irradiation cause its increase. In practical terms, the option for improving dehydration avoidance in sorghum by an increase in epicuticular wax load is limited, largely because the increase in epicuticular wax load beyond a certain high threshold is ineffective in further reducing cuticular transpiration. This threshold is already found in many 'normal' non-bloomless (*BmBm*) sorghums (Jordan et al 1984). The "glossy leaf" trait of sorghum, which is probably associated with the structure of epicuticular wax deposition, was found to improve seedling drought resistance in terms of wilting and recovery (Maiti *et al* 1984). It is interesting that the glossy sorghum seedling (e.g. cv. M-35-1) is also less prefered for oviposition by the sorghum shoot fly. The glossy leaf trait is conditioned by a single genetic factor and it is easily recognized by its wetting characteristics (Tarumoto 1980) and its shiny green color.

Epicuticular wax, in relation to its amount, composition and structure, forms a reflective surface on the leaf. Since the radiative load on the plant canopy is a major energy source for transpiration and leaf heating, epicuticular wax is important in reducing this load (Blum 1975). Glaucous (waxy) varieties of wheat were found to yield better mainly because they sustain less leaf senescence which is caused by high leaf temperatures (Johnson et al 1983). This could also be the reason for the yield advantage under hot dryland conditions of 'normal' over 'bloomless' isogenic lines of sorghum (Ross 1972).

Another means for non-stomatal control over transpiration is leaf area. Leaf area affects light interception by the canopy as well as crop water-use, up to a threshold leaf area. While the maximization of leaf area is desirable for light interception and crop growth, it also involves a greater water-use. while exact experimental results are unavailable, it may be proposed that in a drought-stressed crop leaf area need not be maximized. Under such conditions maximal growth will not be achieved by maximizing leaf area, because of the limitation imposed by water stress. On the other hand, a large leaf area imposes a greater crop water-use. It follows that for varieties intended for stress conditions only, a genetically lower leaf area may prove to be an advantage. This assumption receives support from two sources. Drought resistant landraces of sorghum developed in dry regions in Africa and India (Blum and Sullivan 1986) were characterized by a relatively smaller leaf area, due to narrower leaves. Finger millet (*Eleusine coracana* Gaertn.) genotypes of smaller leaf area were found to be most adapted to rainfed conditions (Sashidher et al 1986). The leaf area of sorghum can be reduced by either reducing the number of leaves (which involves earlier maturity) or by reducing leaf width within any maturity class.

Osmotic adjustment

Osmotic adjustment is being increasingly recognized as a most powerful and effective mechanism of drought resistance in many (though not all) crop plants. Work in sorghum demonstrated that osmotic adjustment was effective in allowing plants to accumulate biomass carbon throughout a water stress cycle with only little metabolic cost (McCree et al 1984). The accumulation of cellular solutes under stress results in a reduced (more negative) osmotic potential, which in turn allows to retain a higher turgor at a given leaf water potential. In other words, osmotic adjustment reduces the stress experienced by cells, for a given leaf water status. As stomatal activity is largely regulated by turgor, osmotic adjustment translates into an ability to retain more open stomata and gas exchange at a given leaf water potential. Thus, the soil-to-leaf gradient of potentials which is essential for driving water transport and transpiration can be maintained at a lower risk of damage to leaf cells and carbon exchange. Evidence on the importance of osmotic adjustment as a drought resistance attribute in crop plants and the fact that osmotic adjustment allows to retain more open stomata and gas exchange under stress should further support the rejection of sensitive stomatal closure as a drought adaptive trait in crop plants.

The capacity of sorghum for osmotic adjustment can be large, and large variations exist in this respect among sorghum genotypes. In a recent study (Blum and Sullivan 1986), various parameters of the plant water relations were investigated in various landraces of sorghum and millet from dry and humid regions in Africa and India, with the purpose of finding the drought resistance attributes that characterize landraces developed in dry regions. Of all 21 parameters tested, only osmotic adjustment was correlated with rainfall at the site of their origin, indicating that the drought resistant landraces developed in dry regions were more effective at osmotic adjustment than races developed in humid regions.

Osmotic adjustment is highly affected by the environment with respect to the pattern of stress. Solute accumulation in response to leaf dehydration is slow and requires time. If leaf dehydration is rapid, leading to a very low leaf water potential within several days, the capacity for osmotic adjustment of a genotype will not be expressed. A crop with a limited root volume or a crop grown on a soil of poor water holding capacity will likely present this problem. The amelioration of root growth and penetration will therefore not only increase the amount of available moisture to the plant but should also reduce the rate of dehydration under stress and allow effective osmotic adjustment to the given limit of the specific genotype.

Leaf rolling is a well recognized response to water stress in many plants, including sorghum. Leaf rolling may present an advantage under stress, probably by reducing leaf area and radiation load on the plant. Leaf rolling is largely mediated by the loss of turgor. Results with sorghum (in preparation) show that leaf rolling is delayed in genotypes of greater osmotic adjustment. Thus, irrespective of the significance of leaf rolling in itself, a delayed leaf rolling under conditions of water stress can be used as a simple integrated criterion for dehydration avoidance and/or osmotic adjustment. A leaf-rolling score is already used as a selection criterion in water-stressed nurseries of rice (IRRI 1982) where less or a delayed leaf rolling is taken as a desirable attribute.

Poor ability for dehydration avoidance and/or osmotic adjustment is expressed in various plant symptoms that are well recognized and can be scored visually. Such symptoms are used extensively in the sorghum breeding program in Texas (Rosenow *et al* 1983). Apart from leaf rolling, plants may present symptoms of leaf firing or various forms of leaf necrosis, which are caused by excessive leaf heating due to low transpiration. Plant heading may be inhibited in extreme cases of stress (O'Neill *et al* 1983, Rosenow *et al* 1983) and a poor head exertion is a reliable criterion for a response to pre-heading stress across genotypes of similar phenology. Where stress is severe enough to cause reduced growth in field nurseries, a "saddle" effect is seen (Rosenow *et al* 1983), whereby plants at the center of the nursery row are distinctly shorter than the plants at its edges, which enjoy a border effect. Thus plants at the edges of the row serve as a "less stressed" control within each genotype and the development of a distinct "saddle" effect is indicative of a poor drought adaptation.

Both dehydration avoidance and osmotic adjustment allow some transpiration to proceed inspite of the increasing drought stress. Transpiration causes leaf cooling. Thus, leaf canopy temperature under conditions of moisture stress may serve as an indirect measure of the integrated effects of dehydration avoidance and/or osmotic adjustment. Superior genotypes, in this respect, are characterized by a relatively lower canopy temperature. Canopy temperatures can be measured very rapidly with the infrared thermometer. The use of infrared thermometry for screening drought resistant genotypes in a water stressed nursery has been developed in wheat (Blum *et al* 1982) to the extent that it is now a routine integral part of the wheat breeding program in Israel. There is no reason why it could not serve the same purpose in sorghum or any other crop, with the proper application and precautions.

Although it may seem to be a trivial statement, experience shows that it should still be made. The selection for drought resistance, in terms of dehydration avoidance and/or osmotic adjustment cannot be performed unless the genetic materials are tested under drought stress conditions. It is paradoxical that while drought resistance is important for the stress environment, this environment is too unstable to be used in selection for drought resistance. Large variations in rainfall between and within years in the semi-arid region do not allow to design a sufficient and proper selection pressure in each year. The truncation of any given population for a response to drought stress requires a proper level of stress at a relevant growth stage. The best solution would be in growing the nursery in a very dry environment and in upgrading the water regime by irrigation to a certain repeatable level of stress. The second paradox is therefore that a good irrigation system is needed for designing an efficient selection program for drought resistance. Irrigation can introduce large spatial errors into the nursery, especially when low rates are used. Surface irrigation is the worst method in this respect, while sprinkler irrigation when properly designed and applied is the least erratic method. The "line-source" sprinkler irrigation system, where materials are subjected to a stress gradient, has been evaluated quite extensively in recent years (Garrity *et al* 1982). O'neill *et al* 1983, Seetharama *et al* 1982). It was found to be very efficient in revealing genetic variations for dehydration avoidance. In sorghum, the rate of heading in response to a pre-heading gradient of water stress was shown to be an effective criterion (O'neill *et al* 1983). The shortcoming of this method is in the requirement for a large installation if a large germplasm is to be evaluated and in the required expertise in sprinkler irrigation.

Conclusion

The selection for a better yield performance under conditions of drought stress requires the recombination of high yield potential with some physiological attribute of drought escape and avoidance. It cannot be performed without a reasonable control over the water stress environment.

Plant phenology should be optimized with respect to the prevailing stress and recovery cycles. Where recovery is relevant it can be visually scored, provided that both stress and recovery are reasonably controlled and that genetic variations in maturity are accounted for.

No singular drought avoidance attribute may be taken as an effective criterion and a combination of several selection indices is essential. For reasons discussed in this paper, the following selection criteria should be considered for genotypes designated for stress conditions: smaller leaf size, delayed leaf rolling, less leaf necrosis and firing, minimal "saddle efffect" in nursery rows and a proper head exertion. Where possible, and after some research, remotely sensed infrared canopy temperatures may be used to replace or supplement various visual assessments of leaf stress symptoms. The above mentioned criteria are largely characteristic of a plant community without any inter-genotypic competition. Selection of single plants at an early stage of segregation is practically impossible at the present state of our knowledge.

As most plant responses to water stress change with plant age, genetic variations in plant phenology must be accounted for by comparing genotypes of similar maturities.

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8 An environmental physiologists approach to screening for drought resistance in sorghum with particular reference to Sub-Saharan Africa*

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Abstract Sorghum *Sorghum bicolor* (L.) Moench is an important food crop of the semi-arid regions of Sub-Saharan Africa but under drought conditions yields have fallen from a long term average of around 1000 kg/ha to below 100 kg/ha.

In view of the range of environments in Sub-Saharan Africa and the different patterns of drought which occur in these regions, breeding for drought resistance in sorghum is a complex problem. A careful analysis of the environment is combined with the identification of appropriate physiological traits for developing drought resistant and higher yielding sorghum.

Historical rainfall data for the sorghum growing locations were analysed for delineation of the average dates of the beginning and end of the rains, the length of the rainy season, and the probabilities of receiving a defined amount of rainfall during the crop growing season. From the computed date of sowing, the duration of drought at various probability levels were assessed on a 10-day interval for the growing season. This information was used to group locations that have similar probabilities of drought in different growth stages of the sorghum crop. Three important growth stages are recognised viz. seedling establishment, mid season growth, and the grain-filling period.

The approach taken to the systematic development of a practical drought screening program is illustrated using data from a mid-season drought situation although it is emphasised that the approach for all three stages is essentially the same.

Initially, a sample of genotypes were selected from the sorghum genetic resources accessions at the ICRISAT Center to represent material collected from many countries over a range of altitudes (0 to 2000 m) and mean annual rainfall (250 to 2500 mm) covering most of the taxonomic groups.

The sample of lines were screened under severe drought conditions at ICRISAT Center, Patancheru, India in the relatively rain-free summer seasons from 1983 to 1986.

Considerable genetic variation was shown in the response and survival of these genotypes to mid season drought and high temperature. Visually observed differences in 'resistant' and 'susceptible' genotypes in terms of desiccation tolerance and recovery ability were shown to be based on measurable physiological responses.

In conclusion, it is argued that although the 'environmental physiology' approach has enabled sorghum scientists to focus their screening efforts on specific drought problems, it is vital that more emphasis is put on developing those types of climatic analysis which better describe the various droughts of Sub-Saharan Africa.

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Introduction

Sub-Saharan Africa (SSA) is the only part of the developing world in which the index of per capita food production has declined during the last two decades (33). Of all the sub regions of SSA, West Africa has shown the slowest growth rate for total food production. Sorghum (*Sorghum bicolor* (L.) Moench), is grown on over 10 million ha in West Africa where it is one of the most important rainfed food crops. In Burkina Faso, for example, 56% of the total calorific food intake comes from sorghum. Despite this the annual-growth rate of sorghum from 1969-71 to 1980-82 in SSA was 2.1% which was lower than the population growth rate of about 2.5% during the same period.

The present sorghum cultivation practices in SSA are vulnerable to the ravages of drought; while average yields of sorghum are around 1000 kg/ha, under drought conditions these have fallen below 100 kg/ha.

It is therefore important to limit yield losses from adverse variations in the environment. As Jordan and Sullivan 1982 stated, "the problem of crop performance under drought conditions resolves into two basic components: the first a genetic component and the second, a management component". There are complex interactions between the two and our efforts to cope with drought must aim at a thorough understanding of the entire production system including environment, management and genotype.

In this paper we emphasize the need to bring our present knowledge of two of the components of this production system, the environment and the genotype together in what is termed an "environmental physiology" approach. The physiological and genetic aspects of crop improvement in response to drought and the associated high temperature stress have been comprehensively reviewed in recent years and will not be repeated here, However, these reviews indicate that ample genetic variation for physiological components of drought resistance exists in sorghum.

An objective of this paper is to emphasise the need for appropriate descriptions of drought environments. Simple methods of rainfall analyses with suitable examples from SSA are described. A further objective is to demonstrate that these analyses provide the physiologists and breeders with sufficient information to focus their screening on a specific drought problem.

Such an approach should also aid in the identification of appropriate genetic variation and physiological traits for developing more drought resistant and higher yielding sorghums for the semi-arid regions of Sub-Saharan Africa.

The environmental physiologists approach

Drought is a complex problem and scientists have made little progress in developing material that is more stable than the local farmers' landraces. We believe that there is a very good reason for this; many of our crop improvement programs have been trying to develop 'improved' material with little or no idea about their real customers or the environment they live in. Initially the most important component to define (rather than drought itself) is the needs of the customer and the environment that he has to grow the sorghum crop in.

We think that the approach is simple and systematic, it has six components which are summarised briefly below under the following headings:

Customer; Environment; Growth stages; Germplasm; Traits; Collaboration.

All components are important but the most important is a clear understanding of the environment where the key person, the customer, is trying to produce food.

Customer

The customer's needs are very important. Researchers often forget that apart from feeding the children the farmer has cattle to feed, food to cook and roofs to cover. The failure of many high yielding varieties (HYVs) has been because these important uses have been ignored.

Environment

It is impossible to develop a crop improvement program for drought prone areas without a clear understanding of the climatic conditions of the area. If we are to focus our research on the type of sorghum genotypes and traits required for any particular customer, it is essential to establish whether the problem our customer has is one of seedling drought stress, mid season or terminal stress or a combination of any two or three. This can only be done through a detailed analysis of the customer's environment.

Growth stages

It is vital that the selection procedure set up will discriminate resistant and susceptible material under stress conditions for the three phenologically distinct growth stages; viz. (i) emergence to about floral initiation (GS1) (ii) floral initiation to flowering (GS2) (iii) flowering to physiological maturity (GS3).

Germplasm

It is essential that the material used has a wide a genetic base as possible. Therefore by germplasm we include both landrace and breeding material. We should also point out that the success of this approach relies more on the use of the landrace material than of breeding material.

Traits

The first part of this component is to visually identify a character or trait which imparts resistance at any one of the phenological growth stages. Many examples could be given but some are good seedling emergence, lack of leaf desiccation during mid-season stress and absence of lodging at the time of terminal stress. All these traits should be easily identifiable. The success of the overall approach depends on selecting both highly resistant and susceptible material.

The second part of this component deals with the physiological measurements on the resistant and susceptible material. As physiologists we should understand the principles that determine why that seedling or plant survived the harsh environmental conditions. Successful development of stable drought resistant material requires good science, coupled perhaps with a bit of luck.

Collaboration

Finally, but not least, is the collaboration component and evaluation of identified traits. As we said earlier, breeding for drought resistance is a complex problem which up to the present has not been solved. It never will be if we work in isolation from our colleagues, not just within ICRISAT, but those working outside of ICRISAT. The collaboration should be international and must include both basic and applied research and evaluation of the important traits and material.

Sub-Saharan Africa (SSA) – the drought problem

In brief, what is important is that we are able to solve our customers drought problems in SSA. Obviously this poses an enormous problem in itself as there are so many different climatic zones and variable rainfall patterns.

Among the environmental factors that are most relevant for a discussion on drought are rainfall, temperature, radiation and soils. Seasonal variation in temperature and radiation at a given site are the most predictable. The most variable factor however is the amount and distribution of rainfall. This, in combination with the variation in the depth and physical characteristics of soils between locations, leads to droughts of varying intensities and durations during the growing season. The first requirement in the analysis of the environment then, as Turner 1982 points out, is the characterization of droughts experienced and expected at different locations.

Unfortunately, in spite of a wealth of information on weather, interpretation of this information in terms of plant response has relied strongly on extensive yield testing. Priority zones for sorghum research continue to be identified on the basis of mean annual rainfall while drought-prone regions continue to exhibit considerable variability in rainfall from year to year and large variations in spatial distribution are common. For example, the variation in mean annual rainfall at Banfora in Burkina Faso (Fig. 1) over the last 64 years is about 25%. Although the mean annual rainfall here is 1148 mm (as represented by the horizontal line), from 1968 onwards the rainfall has been below average and in 1983 it was only 480 mm.

Like most areas in SSA the rainfall in West Africa is variable not only from year to year but also from month to month within the same year. An example of this can be seen in Fig. 2 which depicts the daily mean rainfall at Niamey, Niger, during three years. The mean annual rainfall at Niamey is 560 mm. From this criterion, 1964 was an above-average year, 1968 an average year, and 1972 a year with below average rainfall. However the rains terminated by early September in both 1964 and 1968 while in 1972 it rained till 18 October.

The variations described above cause instability in the traditional methods of crop production and open to question the utility of employing average rainfall data in evolving 'drought strategies'. A rainfall record can provide a wealth of guiding information for agriculturalists but only if the information generated can be used in solving operational problems. Obviously careful analysis of the long term rainfall data is called for. Some of the more meaningful questions that could be asked are:

a) What is the average date of the beginning of the rainy season and what is the variability associated with it?

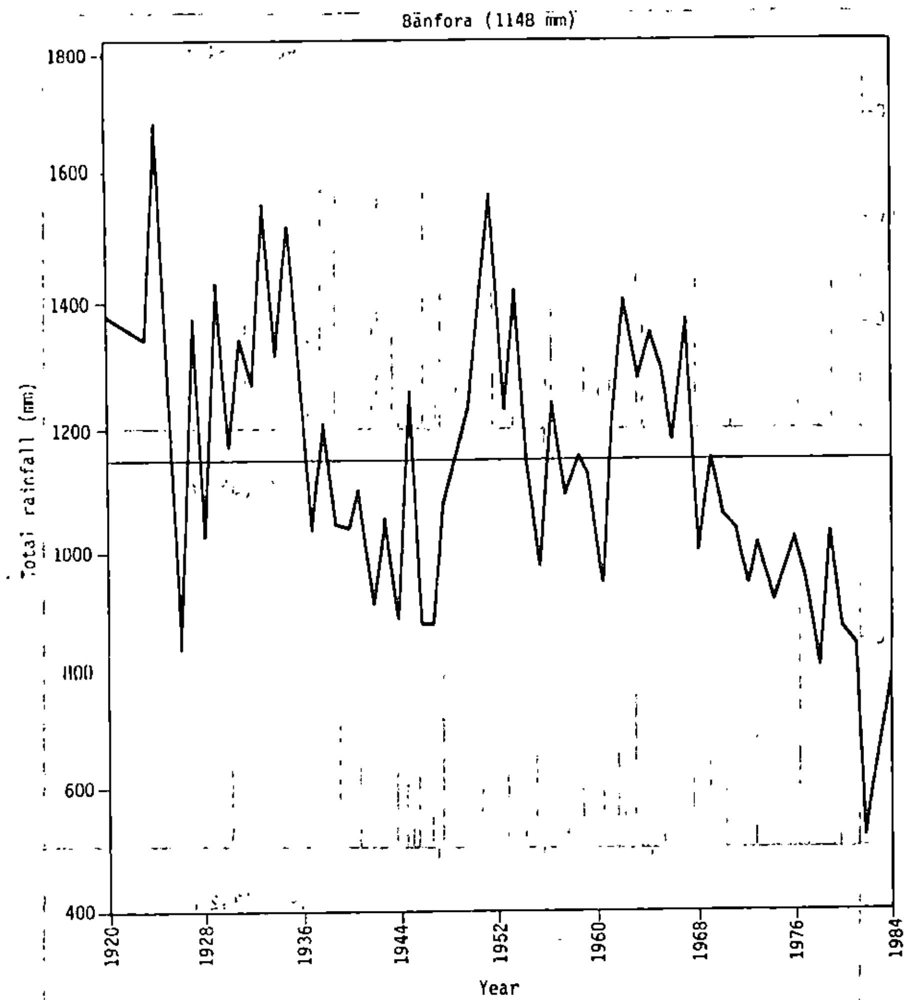

Figure 1 Annual rainfall variation at Banfora, Burkina Faso (Mean annual rainfall = 1148 mm).

b) When do the rains stop and what is the variability of the date when the rains end?
c) What is the average length of the growing season for a particular crop in a given location and what is the variability of this period?
d) Considering the above, what are the criteria to be used in the choice of a variety appropriate to this location?
e) In order to devise strategies for overcoming the effects of drought what are the probable periods of drought stress endured by a given variety?

Rainfall analysis: An example from Sub-Saharan Africa

To illustrate the application of agroclimatic information to answer the above questions, we have chosen five locations in SSA. These are Mopti (Mali) and Niamey (Niger) in the Sahelian climatic zone, Kaolack (Senegal) and

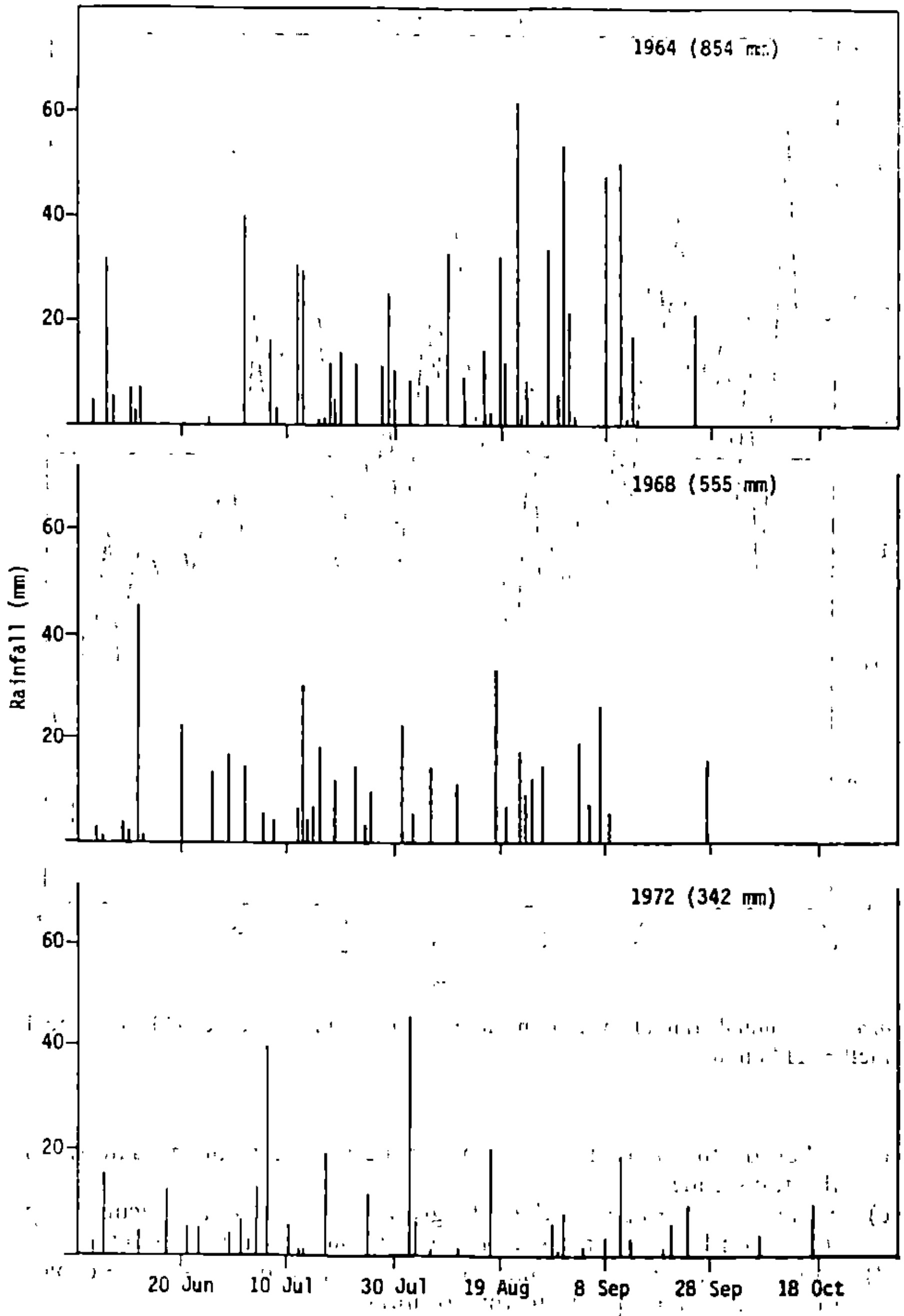

Figure 2 Daily rainfall variation at Niamey, Niger.

Ougadougou (Burkina Faso) in the Sudanian zone and Sikasso (Mali) in the northern Guinean zone.

Monthly and annual rainfall

The simplest analysis of rainfall is usually the calculation of means and variability. Monthly and annual rainfall statistics along with the data base for these five locations are given in Table 1. Mopti and Niamey with a low mean annual rainfall exhibit higher coefficients of variation (CV) than the other locations in SSA, specially in May and October. In general CVs during the rainy months of June to September range from 24 to 9 52% at different locations and the CV for annual rainfall ranges from 17 to 26%.

Considering the high variability associated with the monthly and annual rainfall it is imperative that strategic planning for the drought-prone regions must consider periods shorter than a month. Use of monthly averages to describe seasonal regimes is often suspect not only because moisture availability over a short period of even 10 days is critical but also the onset and the end of the season – either on average or for individual years – do not coincide with calendar months. Hence we have analyzed the daily rainfall data available over a period exceeding 50 years for these locations.

Beginning and end of rains

The date of the beginning of the rains is an important criterion in planning agricultural operations, particularly sowing. Various definitions of the beginning of rains are available. The criterion used here is that of receiving 20 mm of rainfall totalled over 3 consecutive days after 1 May with no period without rain longer than 7 days within the next 30 days. Experience with both sorghum and millet crops in West Africa suggests that this sowing criterion could give satisfactory emergence and plant stand. The date of ending of rains has been taken as the day after 1 September following which no rain occurs over a period of two decades (a decade is a 10 days period). The length of the rainy reason is the difference in days between the dates of the beginning and end of the rains, as defined above.

Table 1 Monthly and annual rainfall (mm) statistics at selected locations

Location	Data base (yrs)	May		Jun		Jul		Aug		Sep		Oct		Annual	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Mopti (Mali)	58	26	100	60	52	146	40	183	39	93	45	19	96	534	23
Niamey (Niger)	78	35	93	76	52	143	37	193	40	90	51	16	100	563	25
Kaolack (Senegal)	56	5	232	60	70	157	49	293	40	211	44	63	76	796	27
Ouagadougou (Burkina Faso)	57	73	67	111	43	181	28	253	35	145	37	35	93	827	24
Sikasso (Mali)	65	113	52	165	32	268	29	334	24	242	37	98	60	1306	17

CV = Coefficient of variation (%)

Using these criteria we computed the dates of beginning and end of the rains and the length of the rainy season for each year of the data base for the five locations in SSA. Computations for each year have been used to calculate standard deviations associated with these dates. Results of this analysis, presented in Table 2, bring out more clearly the following important features of the daily rainfall at the selected locations (Table 1):

a) Rains at the drier Sahelian locations (Mopti and Niamey) begin 20-31 days later and end 25 days earlier as compared to the higher rainfall locations. The standard deviation of the beginning of the rains here is also higher. Hence in dry years the length of rainy season could be considerably shorter in the Sahel.
b) The end of rains is less variable than the start at the five locations in SSA as reflected by the lower standard deviations.
c) At Sikasso, the high rainfall location, the length of the rainy season is 46-52 days longer than at Niamey and Mopti and 13 days longer than at Ouagadougou.
d) Koalack, which has a mean annual rainfall nearly similar to that for Ouagadougou and falls in the Sudanian zone by that criterion, is like the Sahelian locations. The rainy season starts later at Kaolack indicating that much of the rains received earlier in the season are undependable for sowing. The length of rainy season at Kaolack is similar to that at Niamey.
e) The standard deviation of the length of rainy season at Mopti (26 days) and at Niamey (20 days) show that in dry years the length of the rainy season could be very short, viz. 62-74 days, showing thereby the reasons for crop failure in dry years.

Rainfall probabilities

Decadal precipitation totals for a long period of time are available for many of the drought-prone regions in SSA. These data can be analyzed by fitting the most appropriate mathematical function to the rainfall data and computing the probabilities of receiving a certain amount of rainfall, e.g. 10, 20, 30 mm, etc. We have used the Markov chain model for precipitation analysis which was introduced by Gabriel and Neumann 1962 and has been used widely. The application of these models in agricultural planning has been discussed by Stern and Coe 1982. Rainfall probabilities can be effectively used to sow the seasonal progression of rainfall dependability thereby providing a useful means to differentiate locations. This point can be amply illustrated for Kaolack and Ouagadougou which have the same mean annual rainfall. The probabilities of receiving 10 mm or more of rainfall during each decade at Ouagadougou and Kaolack are shown in Fig. 3. At Ouagadougou the rainfall probabilities by decade 12 are 35% but increase to 78% by decade 15 and stay above the dependable probability level of 70% (indicated by the horizontal line) till decade 27. At Kaolack the rains start late (Table 2) and so the probabilities do not reach the dependable level until decade 19 and stay below those at Ouagadougou until decade 21 but thereafter probabilities at Kaolack are higher.

Rainfall probabilities for Mopti and Niamey (Fig. 4) also show a slight advantage for Niamey where the probabilities reach the dependable level by decade 17 in contrast to decade 19 for Mopti. This initial advantage is reflected in the beginning of rains by 7 days and in the length of the growing

Figure 3 Probability of receiving 10 mm or more of rainfall during each decade at two locations in the Sudanian zone.

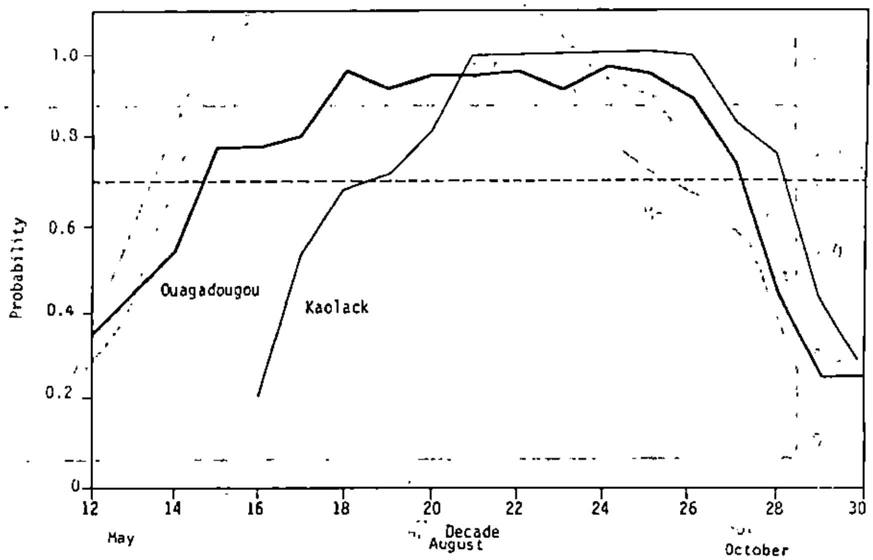

Table 2 Average dates of beginning and end of rains and length of rainy season at selected locations

Location	Beginning of rains		End of rains		Length of season	
	Date	s.d.	Date	s.d.	Days	s.d.
Mopti	19 June	21	15 Sep	11	88	26
Niamey	12 June	17	14 Sep	9	94	20
Kaolack	23 June	14	27 Sep	12	97	18
Ouagadougou	31 May	16	24 Sep	12	117	21
Sikasso	23 May	12	10 Oct	14	140	18

season by 6 days for Niamey (Table 2). At Sikasso the dependable probabilities are attained by decade 14 and continue until deacade 29.

Drought probabilities

The analysis described so far provides useful information about a location but is still insufficient to supply answers to the specific question of probabilities of dry spells since there are occasions when dry spell frequency is more important regardless of rainfall totals. For example, in the case of sorghum it will be useful to have information on the relative susceptibility of the crop to drought spells during the GS1, GS2 and GS3 phases.

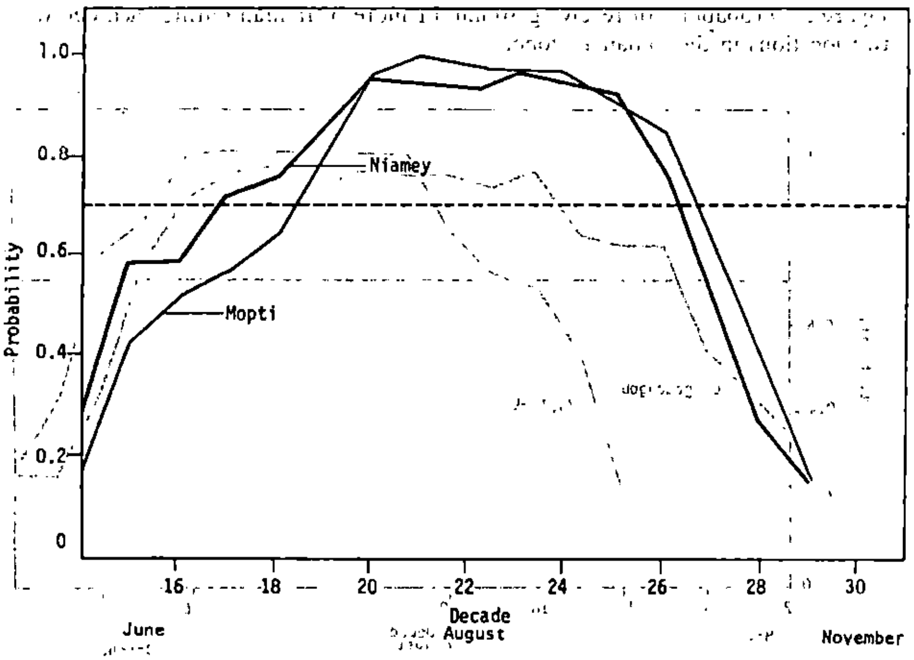

Figure 4 Probability of receiving 10 mm or more of rainfall during each decade at two locations in the Sahelian zone.

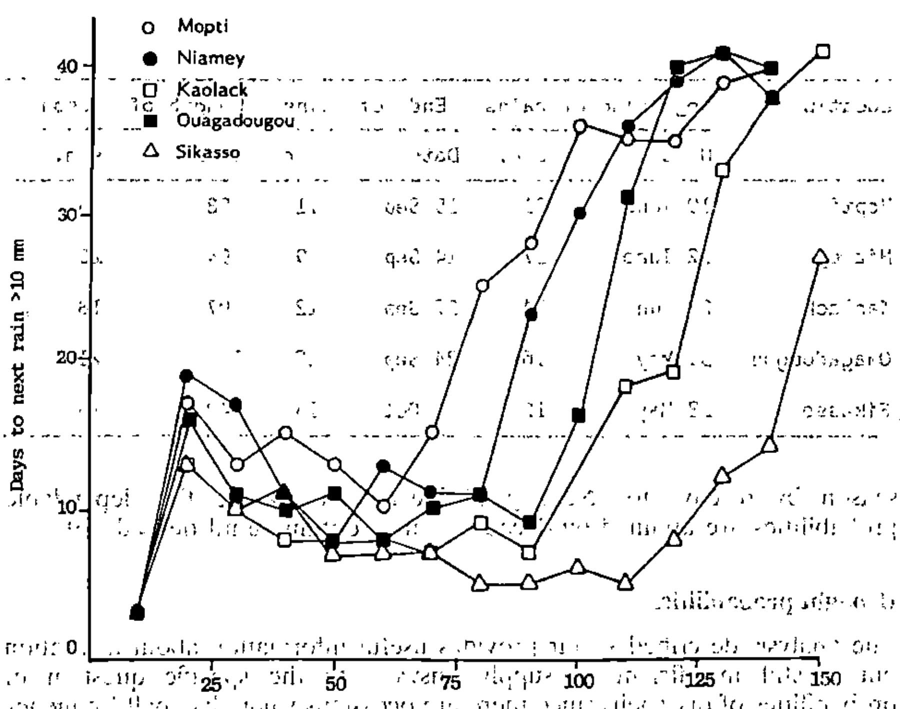

Figure 5 Number of days until the next rainfall greater than 10 mm at 90% probability level at 5 selected locations.

Assuming the computed date of beginning of rains in each year (defined previously) as the date of sowing, the length of dry spell (or days until next day with rainfall greater than a threshold value) at different probability levels can be computed for consecutive 10 day periods from sowing. Results of this analysis for the selected locations at a 90% probability level shown in Fig. 5 emphasise the following important points:

a) The dry spells during GS1 are more probable than those during GS2, specially at the low rainfall locations Mopti and Niamey.
b) At Mopti the length of dry spells is progressively longer during GS3 from 80 DAS and at Niamey from 90 DAS.
c) Kaolack and Ouagadougou with nearly similar mean annual rainfall show important differences in the length of dry spells as in the case of rainfall probabilities (Fig. 3). At Kaolack the length of dry spell is progressively longer form 100 DAS while at Ouagadougou this happens from 120 DAS.

Since the dry spell analysis shown in Fig. 5 is based on the computed date of sowing for each year of available rainfall data, these data could be used as a guide for the various maturity durations of varieties to breed for in different locations. At Mopti and Niamey breeding strategies should be oriented towards maturity durations of 80-90 days, for Kaolack 100 days, for Ouagadougou 110-120 dyas and for Sikasso 140 days. So far in this chapter we have attempted to better define some of the environments of SSA, but how can the physiologists use this information to solve the drought problems in Mopti, Niamey, Kaolack etc.

These data and the conclusions listed above provide essential information for the physiologists and the breeders for developing more stable yielding varieties for these five locations. Clearly physiologists and breeders from these locations should now concentrate on screening the sorghum material for those traits which will impart resistance during GS1 and GS3. However although many other locations in SSA have similar drought distributions to the five locations described, there are those such as the central region of Tanzania where there are mid season or GS2 droughts.

The next step in this paper is to describe those stages, of the components of the 'environmental physiologists' approach, that lead to the development of more stable and higher yielding lines for GS1, GS2 and GS3 stress environments. Although screening methods have been developed by ICRIAT scientists for all three stress environments it will not be possible to describe more than one in this paper. Our aim is to also demonstrate that the overall approach, irrespective of the particular growth stage (ie. GS1, GS2 or GS3) at which the stress occurs, is similar.

Screening methods for identifying good crop establishment traits in both sorghum and millet have been published and these are also described by Soman *et al.* 1986 in these proceedings. Similarly the important traits associated with GS3 were extensively reviewed in 1983 at the Bellagio workshop in 1984. Consequently we will concentrate on a mid-season stress situation, and go systematically through our approach for a location in India.

The environmental physiologist's approach – an example from India

Customer

Farmers at Anantapur who grow sorghum for food and fodder.

Environment

The mean annual rainfall at Anantapur is 590.2 mm, very similar to Mopti and Niamey but the distribution is very different. Fig. 6 shows that the drought problem is one of mid season stress.

As a result of the distance from Patancheru and the poor resources available at Anantapur it is impossible to conduct all the research at that location. Some of the more detailed research had to be undertaken at Patancheru.

Unfortunately the normal growing season at Patancheru, in the absence of a "rain-out" shelter, does not enable us to do this and therefore it was necessary to simulate mid-season stress conditions 'out of season'. This was done, by growing material in the summer season (i.e. March to the onset of rains in June).

Growth stage

The growth stage is GS2 and is usually associated with the growth from about the time of floral initiation to that of anthesis or 50% flowering. However, the onset of the stress may occur before initiation, particularly with late maturing varieties.

Germplasm

It would be extremely difficult to systematically screen the 26000 accessions of sorghum that have been collected so far. Thus, a representative sample was selected. In 1983, a total of 700 selected germplasm accessions and

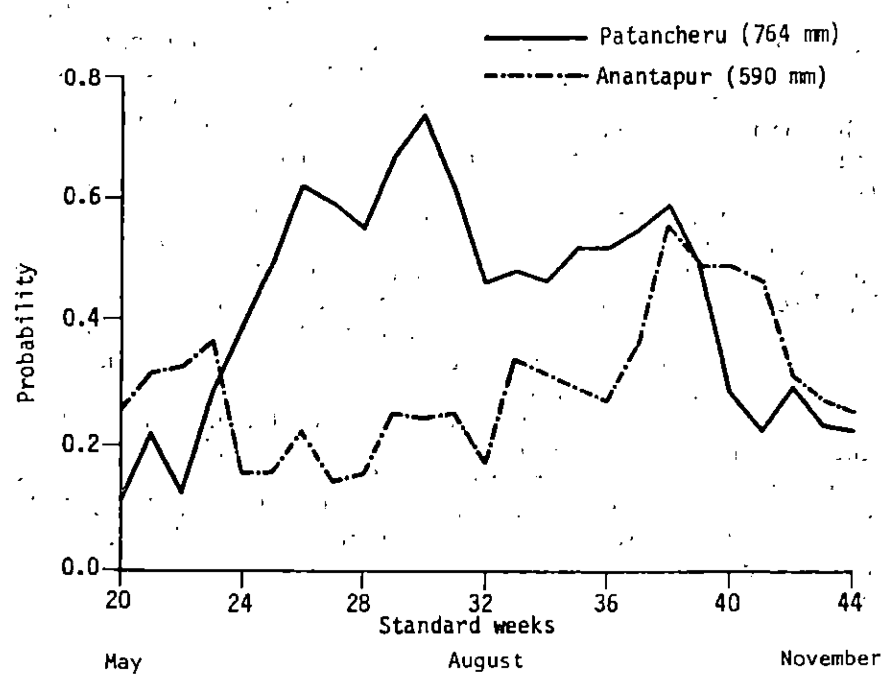

Figure 6 Probability of receiving 20 mm or more of rainfall during each standard week at two locations in India.

advanced breeding lines were screened during the summer (March-June) at ICRISAT Center. The material was divided into three groups; the first two comprised germplasm lines selected from a wide range of taxonomic groups (e.g. durra, caudatum, etc.), geographical locations (countries where sorghum was collected), and climates (range of altitudes and mean annual rainfall). The third group included both germplasm and 70 advanced breeding lines developed at ICRISAT or by national programs. The material was sown in mid March and established with irrigation for 15 to 18 days. Irrigation was then discontinued and the midseason stress imposed.

Traits

Many physiological traits that affect crop adaptation to drought and high temperatures have been identified and a "physiological approach" to breeding for drought resistance has been described by Morgan 1980, Bidinger 1980 and Steponkus *et al.* 1980. However, in the early stages of our screening program it was essential to examine only those traits that could be visually recognised. The two traits examined were:

1. Desiccation tolerance, i.e. a measure of the amount of leaf area that remained unscorched or "fired'. We scored leaf firing at regular intervals during the stress period on a 1 to 5 scale, where 1 = less than 20% of leaf-area fired, and 5 = over 80% leaf-area fired.
2. Recovery ability, i.e. ability of a previously stressed line to produce new leaves and grain after rain. We scored recovery ability on a 1 to 5 scale where 1 = over 80% of the plants in a row recovered, and 5 = less than 20% recovered.

We examined the results of the 1983 screening and retained lines that had a leaf firing score of less than 3 (most resistant) and those having more than 4 (most susceptible). Fig. 7 shows the effects of stresses due to heat and lack of water on a typically 'resistant' and 'susceptible' line. We selected 266 lines for further screening in 1984.

These selected lines were sown on 16 March 1984 in an Alfisol at ICRISAT Center with four replications. The crop was established with irrigation (soil brought to field capacity) and midseason stress imposed by witholding irrigation from 20 DAS. All the lines experienced stresses from heat and lack of water for a period of 66 days. During the stress period only 4.5 mm of rain fell, and the mean maximum temperatures were close to 40°C. The stress ended at 91 DAS, following 21.6 mm of rain. We scored the material for leaf firing at 48, 61, 70 and 83 (DAS), for recovery ability at 89, 94, 102, and 117 (DAS), and for grain yield when the lines reached physiological maturity.

The visual screenings in 1983 and 1984 clearly demonstrated that there were marked differences in the response of these sorghum genotypes to high temperature and water deficit. It was argued that our screening approach could be simplified even further, if the underlying mechanisms associated with these striking differences (Fig. 7) were understood.

Survival (maintenance of membrane integrity) is ultimately determined by the plants' ability to maintain an internal water status which will allow it to sustain a minimum of essential metabolic processes such as photosynthesis and respiration, and to facilitate transpirational cooling of leaves. The apparent failure of some of the genotypes in the earlier screenings were a consequence of one or more of the following:

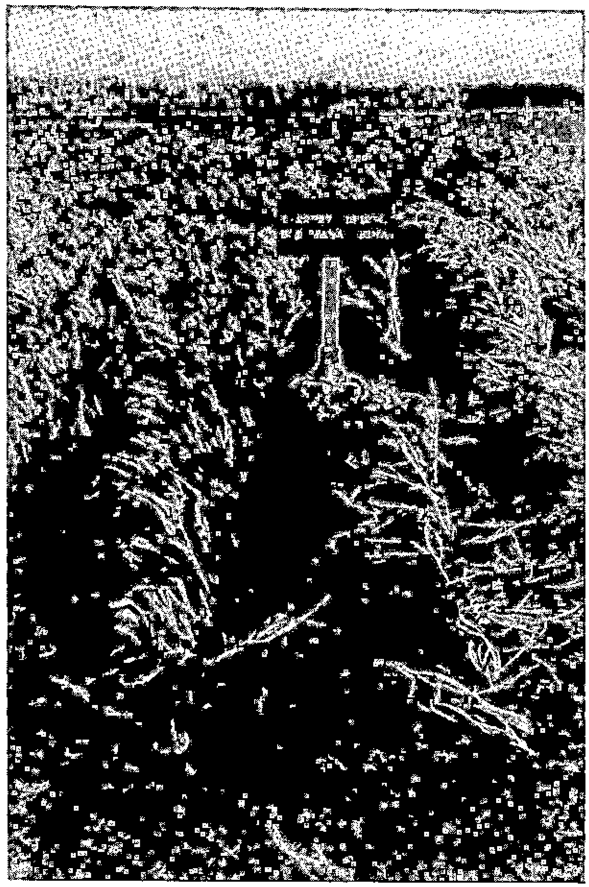

Figure 7 Effects of stresses due to heat and lack of water on two sorghum cultivars, IS 22327 (left), a resistant line from Botswana, and IS 12741 (right), a susceptible line from China, ICRISAT Center, 1984. (Source ICRISAT Annual Report 1984).

1. An inadequate root system, which was unable to extract water to sustain atmospheric demand.
2. Stomatal behaviour which is over sensitive to plant water deficit and high evaporative demand.
3. The cell and leaf tissue is unable to survive at temperatures above 40°C.

From the 266 lines sown in 1984 only 157 flowered by the end of the recovery period. Of these we selected five 'susceptible' lines (FS) and four 'resistant' lines (FR) (Table 3) for a detailed experiment, to examine the physiological bases of resistance to mid-season heat and drought stress.

Instrumentation was installed in two replicates of each of five genotypes in stress and control treatments. The lines measured are marked with an asterisk in Table 3 and represent an early and a late maturing 'susceptible' line and two early and one late maturing 'resistant' lines. Full details of this instrumentation and the physiological measurements are given by ICRISAT 1986 and Peacock *et al.* 1985.

In brief, the following measurements were made on the youngest fully expanded leaf: relative leaf water content (RLWC – defined as the ratio of

Table 3 Sorghum lines used in detailed physiology experiment at ICRISAT Center, summer 1985.

Sorghum line	Origin	Elevation (m)	Annual Rainfall (mm)	Taxonomic group	Time to 50% flowering
Susceptible 1					
*IS 17605	Yemen	1970	600	Durra	131
*IS 12739	China	-1	-	Caudatum bicolor	50
IS 12744	Taiwan	-	-	Guinea caudatum	53
IS 21436	Malawi	75	800	Durra	56
IS 22253	Botswana	1250	514	Kafir	52
Resistant (FR)					
*IS 20969	Kenya	1100	1500	Caudatum	115
*IS 1347	Egypt	-	-	Caudatum bicolor	48
*IS 13441	Zimbabwe	-	-	Caudatum	60
IS 22380	Sudan	600	450	Caudatum	85

1 = Data not available
* = Measurements taken

leaf water content at sampling to that at full turgor), leaf water potential (ψl – as measured with a pressure chamber) and stomatal conductance (gl – measured with a diffusion porometer). Measurements of light incident on the leaves, (Si), and the leaf temperature, (tl), at the time and site of measurement of conductance were made with a quantum sensor and an infrared thermometer, respectively.

Measurements of ψl, gl, Si, and tl were made on the same leaves. Immediately after the measurements of gl, Si, and tl, the leaf was excised and returned to a field laboratory for measurements of ψl and RLWC. Soil water content was measured in these plots, using a neutron probe. Detailed measurements continued until the onset of the rains at 84 DAS after which only dry matter production and grain yield were measured.

The purpose of this paper was not to examine in detail the data from these physiological experiments but to illustrate that it is possible to systematically screen the germplasm and breeding lines. Also, by setting the correct 'selection pressure', it was possible to rapidly identify material from which it may be possible to obtain drought 'resistance' genes. We selected three sets of data.

Results shown in Fig. 8a and 8b clearly demonstrate that, after a critical level of stress is reached (56 DAS), the 'resistant' lines have a very different

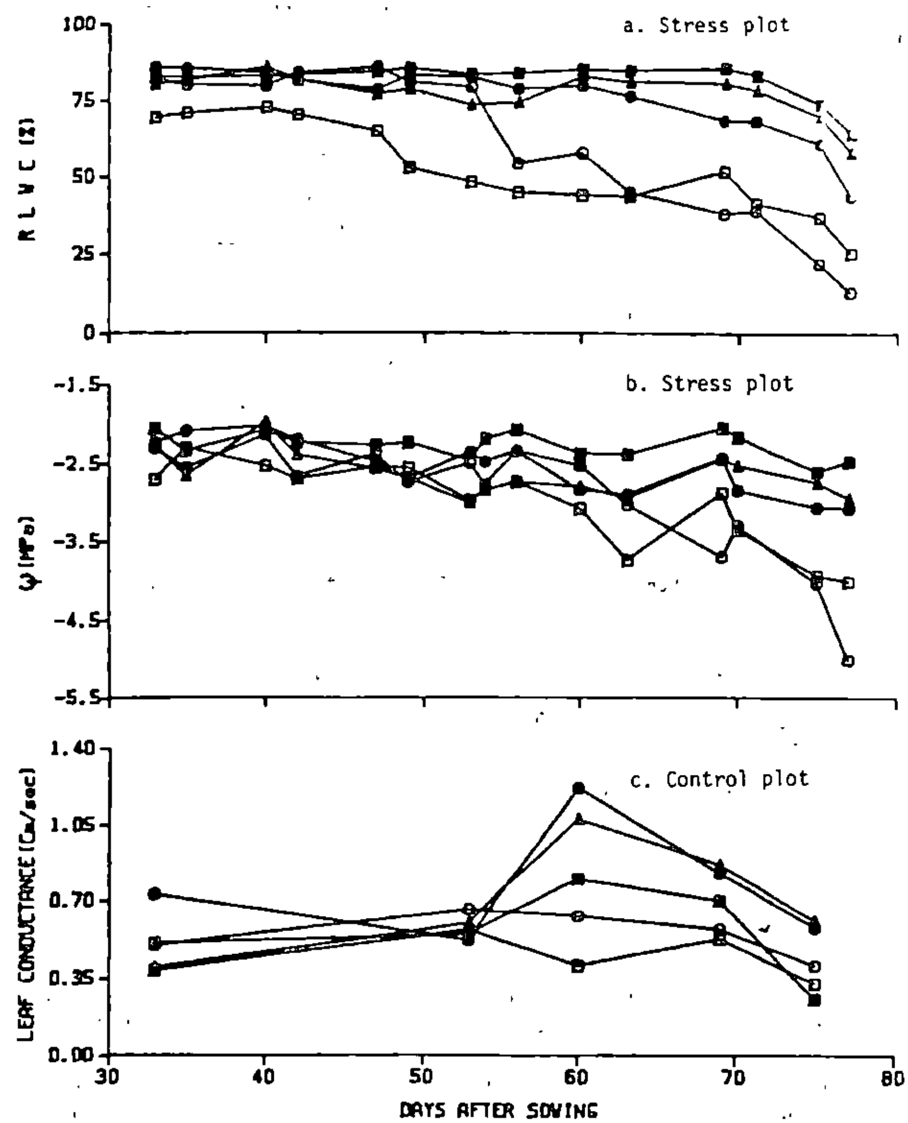

Figure 8 Measurements made at 12.30 h on the midportion of the youngest leaves in five sorghum lines IS 20969 (■), IS 13441 (▲), and IS 1347 (● (resistant), and IS 12739 (○) and IS 17605) (□) (susceptible) of (a) relative leaf water content (RLWC %) and (b) leaf water potential ψl MPa in the stress plots and (c) leaf conductance (gl cm sec−1) in the control plot, ICRISAT Center, summer 1985. [From Peacock *et al.* 1985.]

plant water status to the susceptible lines, in terms of RLWC and ψl under both soil and atmospheric water stress. Noticeably, the trend for both traits is the same. A similar response, under atmospheric water stress only is shown in Fig. 8c for stomatal behaviour in terms of individual leaf conductance, gl. The terminology requiring phrases such as 'resistant' and 'susceptible' was obviously subjective, based on the earlier visual scorings. Yet these data verify that these visual differences are based on measurable physiological traits and could be used effectively in an improvement program to identify 'resistant' genes.

Collaboration

We have little information on the more basic characteristics of these constrasting lines. To date, most of the significant collaborative basic research has been done at the seedling stress stage or earlier. An example of this research is a Ministry of Overseas Development Project (R3801) being conducted at the Welsh Plant Breeding Station (WPBS), in the UK. Earlier, using techniques developed at ICRISAT Center we have shown considerable genetic variation in the ability of sorghum seedlings to emerge at high temperatures. The biochemists at the WPBS, working with the same genotypes, showed clearly that the differences in seedling emergence were closely related to the rates of embryo-protein synthesis. Such collaborative research has not only enabled us to jointly develop a more rapid screening method, but has led to an understanding of some of the underlying mechanisms influencing crop establishment at high temperatures. In the meantime in the area of mid-season stress collaborative research on the applied side has been going on with the Andhra Pradesh Agricultural University (APAU) at Anantapur where lines are evaluated under a typical mid-season stress. In 1985 we obtained excellent correspondence between results at Patancheru and Anantapur.

Figure 9 Sorghum cultivar IS 13441 from Zimbabwe with firing resistance and ability to recover from severe stress. This line has also produced good grain yields on large panicles (left). Source ICRISAT Annual Report 1984).

Conclusions

The approach described has enabled sorghum scientists at ICRISAT Center to focus their screening efforts on specific drought problems and identify important traits associated with that particular drought. This information is also useful in the rapid screening of environments for the choice of suitable testing sites for breeding material, thereby eliminating the present empirical, ad hoc methods of yield testing.

However, we are still some way from our goal as these identified traits have yet to be incorporated, by conventional breeding methods, into better agronomic backgrounds. However, some of the so called germplasm accessions, such as IS 13441 from Zimbabwe, (Fig. 9) are not only a source of these useful traits but also have relatively high yields. It is also encouraging to learn that one of the promising lines, IS 22380 from Sudan, is being used as a parent in Burkina Faso.

Looking to the future, regional programs like SAFGRAD, the national programs and international Centers engaged in agroclimatology should put more emphasis on developing those types of climatic analysis that can better describe the various climatic zones, soils and droughts of the SSA, and at the same time can be used by breeders and physiologists.

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9 Breeding Sorghum Hybrids for Irrigated and Rainfed Conditions in the Sudan

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Introduction

Grain sorghum [*Sorghum bicolor* (L.) Moench] is the most important food crop in the Sudan. With over one third of the crop land in the country devoted to sorghum, it ranks first in total tonnage of grain produced and total area cultivated. Every year some 75% of the total cereal production in the Sudan is generated from sorghum. In most years, the total area under sorghum is over 3 million hectares and over 2.5 million metric tons of sorghum grain is produced. In contrast the total production from all other cereals (millet, wheat, rice and maize) is less than one million tons. Following the 1984 drought, over 4 million hectares of sorghum were planted in the 1985 crop season and resulted in a large production surplus in the current 1985/86 marketing year.

In Sudan, sorghum is the main staff of life for millions of people. In many parts of the country, the crop is wholly utilized. The grain is used for making *kisra* (unleavened bread from fermented dough); a significant portion is also used as thick porridge, *asida*; as a popular beverage, *abreih* and as a local beer, *marisa*. The stalks are used as building material and the straw is used as animal feed or as fuel. Sorghum is thus the nutritional backbone of the country.

Rationale for Hybrid Sorghum Research

The decision to develop an expanded hybrid sorghum research program in Sudan was timely and important. In the Central Clay Plains, mechanized sorghum production on increasingly large farms created the demand for short, combinable, sorghum types. Work in the region by the Agricultural Research Corporation (ARC) over several years had clearly demonstrated that traditional local varieties were late, tall and unadapted to the large mechanized farming operations. As a result, there was a conscious effort by the ARC to undertake intensive selection for high yielding cultivars suitable for mechanized types within the otherwise good local land race varieties. In much of the rainlands seasonal precipitation is usually unpredictable and unreliable with the result that yield reductions and crop failures are common in some years. It has been widely demonstrated that sorghum hybrids have higher yield potential and greater stability under stress conditions than varieties. Hence from the outset it was believed that superior sorghum hybrids identified under local conditions in Sudan could rapidly increase and stabilize yield levels in the rainlands.

History of Hybrid Sorghum Research in the Sudan

Early Years

Research on evaluation of the potential of sorghum hybrids started at Tozi and continued at Abu Naama. Initial efforts concentrated on evaluating introduced commercial hybrids from the U.S.A.; but later sorghum research activity included local development of experimental hybrids. The first local hybrid synthesis was made in 1962 using 30 Sudanese locals (male parents) and a male sterile (female) line. 602A introduced from the U.S.A. Even large scale seed production of a sorghum hybrid from U.S.A. (RS 630) was attempted at Abu Naama in 1963. These early efforts to develop and evaluate the potential of sorghum hybrids for the Sudan were not however pursued.

A breeding program on sorghm hybrids was later reinitiated in the early 1970's in cooperation with the Arid Lands Agricultural Development (ALAD) program, centered in Lebanon. Many ALAD hybrids were evaluated at the Gezira Research Station and new experimental hybrids synthesized locally during winter off-season using parental lines introduced from ALAD.

Recent Developments

In 1977 the ICRISAT-Sudan Cooperative Program for Sorghum and Millet Improvement, supported by the UNDP, was initiated with the mandate of strengthening sorghum and pearl millet improvement research in the country. With the advent of the ICRISAT-Sudan Project hybrid sorghum improvement research received the continuity it needed. Through the cooperative program the assignment of the first full time sorghum breeder in the country was also made.

Today the hybrid sorghum improvement activity at the GRS is a fullfledged program receiving the full attention of the national program. The program benefited from interaction and cooperation with both ICRISAT and INTSORMIL. With support from both ICRISAT and INTSORMIL, an array of useful germplasm has been accumulated, staff have been trained, and technical assistance continually provided.

Breeding Strategy and Organization

Definition of Production Environments

Sorghum is grown in all regions of the Sudan from the arid North to the high rainfall climate of the Southern region. However the bulk of the sorghum crop in Sudan is produced in the Central Clay Plains which includes the provinces of Kassala, Gezira, Blue Nile, White Nile, and Southern Kordofan. This area essentially constitutes the sorghum belt of the country and accounts for over 65% of the total sorghum production in the Sudan. Over 90% of the total sorghum acreage is rainfed and a large portion of that is mechanized.

The following production environments characterize and represent the conditions of the sorghum growing zones in the Sudan:

1. Low rainfall, light soil
2. Low rainfall, heavy soil

3. High rainfall, heavy soil
4. Irrigated, heavy soil

In the sorghum breeding program, attention is given to ensure that these zones are consistently represented in the identification of test locations.

Accumulation of Germplasm

Considerable effort was made to introduce and evaluate an array of A & B (female) and R line (pollinators) parents, at producing and evaluating experimental hybrids in as many locations as possible, and evaluating Sudanese sorghums for their fertility reactions. Earlier in the program, A & B line introductions from ICRISAT Centre and INTSORMIL institutions, primarily Purdue University and Texas A&M University, were characterized and evaluated both under irrigated and rainfed conditions. The most promising five seed parents (TX623, 2219A, 296A, CK74A, IS10360A) were identified to serve as tester parents for all pollinator parents tested in the program. TX623A proved to be the most useful female parent both for seed yield potential and combining ability with local and exotic germplasm.

A large and diverse pool of pollinator parents, mostly introductions from various programs was also accumulated and evaluated in locations with good potential for hybrid seed production. As new selections are made from introductions and progenies of local breeding material, they were immediately utilized for synthesis of new experimental hybrids using the standard set of promising A lines as testers. As the program developed, the varietal and hybrid improvement programs became well integrated and balanced, both with regard to logistic arrangements and germplasm flow.

Training of Personnel

Effort directed towards increasing the capability of technical support personnel was successful. Staff were trained in the technical routine of handling large nurseries, on the synthesis and evaluation of experimental hybrids, selection, maintenance and evaluation of parental lines from various source materials, and the overall concept of hybrid sorghum research improvement vis-a-vis a varietal improvement program. Staff were also trained in the routine and discipline of conducting sound field evaluation of experimental hybrids in various test locations.

Testing Procedure

The synthesis and evaluation of experimental sorghum hybrids in the program was conducted following a stepwise testing procedure (Table 1). Initially several hundred hybrids were generated by test-crossing a large group of diverse pollinator lines on a few established A lines and vice-versa. These were evaluated in single row observation nurseries under irrigation at Wad Medani and under rains at Gadambalia – as New Experimental Hybrids (NEH) observation nursery. In the second stage experimental hybrids that looked better adapted and promising (approximately 10%) on the basis of relevant data collected on NEH were resynthesized during the ensuing off-season for a preliminary replicated yield evaluation as Selected Experimental Hybrids (SEH) preliminary yield trial – at Gadambalia and Wad Medani. In the final stage, the most elite hybrids that filtered through the first two stages of screening were again resynthesized and put together in a multilocational yield trial as Elite Experimental Hybrids (EEH) yield test. The EEH trials were planted in several test locations representing the major sorghum growing zones in the country.

Use of Off-season Nursery

As the hybrid program expanded, the bulk of the offseason activities concentrated on synthesis of new experimental hybrids and regeneration of promising hybrids for multilocational re-evaluation. The availability of a frost-free environment, an excellent irrigation facility, a well trained team of field technical personnel, and good financial support from ICRISAT/UNDP facilitated this very important function of the hybrid program.

Multilocation Testing

As part of the breeding strategy developed for the hybrid program, at least one test location in each sorghum production environment was identified for use in experimental hybrid testing. Many of these test sites were already in place as part of the network of ARC sub-stations. However, where there was no established experiment station, land was negotiated with farmer(s) in the area. Testing was also conducted at several locations in cooperation with other government organizations. This network of test locations provided useful data that were very essential for a meaningful evaluation of breeding material and experimental hybrids.

Development and Release of Hageen Dura-1

Performance Comparison

i. 1979-1981 Seasons

Extensive testing of experimental hybrids started in 1979. Since then, several hundred experimental hybrids were routinely evaluated under irrigated and rainfed conditions of the Sudan. At the end of the 1981 crop season an assessment was made of the performance data accumulated during the previous seasons, and 3 elite experimental hybrids with consistently higher yields over local varieties were identified. Data summarized over 3 years (1979-1981) depict that the 3 elite hybrids have a combined yield superiority of about 50% over local, open pollinated varieties under irrigated and rainfed conditions (Table 2).

ii. 1982 Season

To clearly establish superiority of the newly developed hybrids over both improved and unimproved local open pollinated varieties a final multilocational yield evaluation trial was conducted, in the 1982 crop season in 18 locations representing both irrigated and rainfed situations of the country. Data from 14 locations of this regional trial are reported here. Table 3 summarizes the grain yield data from nine irrigated stations in the Masalamiya and Centre Groups of the Gezira Scheme. The 3 elite experimental hybrids, namely EEH-1, EEH-2, and EEH-3 gave an average grain yield superiority of 34%, 45% and 37%, respectively over the improved local variety Dabar 1/1; and 87%, 101%, and 90%, respectively over Dwarf White Milo, the most commonly grown variety in the Gezira.

Table 1. Number of experimental sorghum hybrids developed and evaluated in a stepwise testing producedure during 1979-1982 crop seasons in the Sudan.

	Trials	1979	1980	1981	1982	Total
1.	New Experimental Hybrid (Initial Obs. Nursery)	519	754	1580	180	3033
2.	Selected Experimental Hybrids (Preliminary Yield Trials)	-	55	47	100	202
3.	Elite Experimental Hybrids (Advanced Yield Trial)	-	-	28	28	56
	TOTAL	519	809	1655	308	-

Table 2. Summmary of yield performance of 3 promising experimental hybrids during 1979-1981 crop seasons under irrigated and rainfed situations.

Hybrid	Irrigated (Wad.Medani) kg/ha	% local	Rainfed (Agadi) kg/ha	% local	Total kg/ha	% local
EEH-1	6389	172	1915	158	4152	165
EEH-2	4093	113	1248	102	2670	107
EEH-3 (Hageen Dura-1)	5203	148	2580	212	3891	180
Mean	5228	144	1914	157	3571	151

Table 3. Mean Grain Yield (kg/ha) of the 1982 Advanced Regional Testing of Elite Experimental Hybrids at Irrigated Locations.

Cultivar	Gezira Res.St. Farm	Bara-kat	Seed Farm	El Tayiba	Medina	Abdel Hakim	Abdel Rahman	Saa dalla	Abdel Galil	Mean	% Dabar	% DWM
EEH-1	7183	7305	5338	6681	5170	2753	3370	2657	1381	4649	134	187
EEH-2	7391	7871	5392	7411	6473	2456	3691	2676	1693	5006	145	201
EEH-3	6749	7324	5066	6955	4470	2996	4476	2899	1732	4741	137	190
EEH-4	6662	6951	4297	6681	3492	1998	2721	2040	1381	4024	116	162
EEH-5	7703	7507	4712	7118	3581	2824	4055	2796	1068	4596	133	185
EEH-6	7148	7695	4360	6903	3701	3074	3037	2274	1615	4423	128	178
Local-1 (Dabar)	5379	6195	4024	4897	2933	1561	2794	2573	808	3463	100	139
Local-2 (DWM)	4008	3984	2608	3920	1940	1106	1732	1880	938	2491	72	100
Mean	6530	6854	4475	6321	3970	2383	3235	2475	1327	-	-	-
Sd	237.3	299.1	437.6	456.4	700.2	428.8	401.2	184.9	NS			
CV %	3.6	4.4	9.8	7.2	17.6	17.9	12.4	7.5	19.9			

Table 4 provides yield data from five rainfed locations in the Central Clay Plains. The 3 elite hybrids out yielded the locals significantly at most of the rainfed locations, as well. EEH-3 was far more superior under rainfed situations with average grain yield in excess of 3 tons/ha and out yielding both improved and unimproved locals by over 40% (Table 4). EEH-1 and EEH 2 also gave yield superiority of 22% and 25%, respectively over Dabar.

iii. Overall Performance

A summary of yield performance of the 3 experimental hybrids over four crop seasons and a total of 27 yield trials (Table 5) showed a combined yield average of 49% over open pollinated varieties that were used as checks. EEH-1 and EEH-3 both gave an overall yield of over 4 tons/ha while EEH-2 averaged about 3.5 tons/ha over all trials.

Seed Production

During the 1982 crop season, an experimental seed production testing of the most elite 3 hybrids, each on a one acre area, was carried out to identify the most elite hybrid that could be produced without difficulty. This exercise was useful also in getting first-hand experience on some of the problems involved in a hybrid seed production operation. The results, as depicted in Table 6, indicated that two of the elite experimental hybrids, EEH-1 and EEH-3, were readily producible, with both the female and male parents flowering at about the same time. EEH-1 gave seed yield of 1.9 tons per acre, whereas EEH-2 yielded 1.7 tons per acre. The third elite hybrid, EEH-2 had its parents poorly nicked, and was thus not readily producible.

Table 4. Mean Grain Yield (kg/ha) of the 1982 Advanced Regional Testing of Elite Experimental Hybrids at Rainfed Locations (with and without supplemental irrigation).

Cultivar	Sennar Main	Sennar West	Samsam	Gadam-balia	Abu Naama	Mean	% Dabar	% Local-2
EEH-1	6482	3300	1826	1367	651	2725	122	129
EEH-2	6753	3616	1779	1287	518	2791	125	132
EEH-3	6967	3590	2088	1708	1346	3140	141	148
EEH-4	6450	2824	1393	1329	1191	2637	118	124
EEH-5	5379	3072	1627	1666	1789	2707	121	128
EEH-6	7310	2960	1807	1637	1470	3037	136	143
Local-1(Dabar)	4010	2579	1482	1033	2040	2229	100	105
Local-2(Variable)	3692	1296	1396	1075	3135	2119	95	100
Mean	5880	2905	1675	1388	1517	-	-	-
Sd	843.2	NS	NS	NS	476.8	-	-	-
CV %	14.3	30.2	27.0	20.9	31.4			

Quality Testing

Bulk seed harvested from the set of the 1982 Advanced Regional Testing of Elite Experimental Hybrids grown at the GRS farm was supplied to the Food Research Centre at Shambat for quality testing. Chemical analyses, determination of milling properties, physical characterization of the grains, and *kisra* baking quality at the Food Research Centre of the ARC indicated that Hageen Dura-1 possessed quality traits comparable to local sorghum varieties.

Recommendation and Release

The results from 27 yield tests over 4 crop seasons along with the experimental seed production and food quality tests were documented and presented by ARC to the Sudan Plant Propagation and Variety Release Committee in January 1983. On the basis of this document the Committee at its 24 January 1983 meeting officially released one of the experimental hybrids and renamed it "Hageen Dura-1", arabic for "Hybrid Sorghum No. 1."

Hageen Dura-1 has several useful attributes, the key ones being its high yield and stability across years and environments. The results of extensive experimental yield testing in the Central Clay Plains, over 4 crop seasons, (1979-1982) indicated that Hageen Dura-1 gave an average yield of 5189 kg/ha or 158% of the local variety under irrigation and 2968 kg/ha or 152% of the local variety under rainfed conditions (Table 5). The hybrid is thus adaptable to both irrigation and rainfed conditions. It is early maturing and possesses good milling and food quality characteristics. Hageen Dura-1 is also easily producible. Productibility of a hybrid is an important determinant of the eventual success of a new commercial hybrid. Ease of seed production certainly helped in the spread of Hageen Dura-1.

Table 5. Summary of yield performance of 3 promising experimental hybrids over four crop seasons (1979/1982) under irrigated and rainfed situations. (A total of 27 yield trials.)

Hybrid	Irrigated kg/ha	Irrigated % local	Rainfed kg/ha	Rainfed % local	Total kg/ha	Total % local
EEH-1	5816	178	2408	123	4112	157
EEH-2	4782	146	2207	113	3495	134
EEH-3 (Hageen Dura-1)	5189	158	2968	152	4078	156
Mean	5262	161	2528	129	3895	149

Growth and Expansion of Hybrid Sorghum Acreage

Factors that Helped Promote Use of Hybrids

The modest success in the hybrid sorghum program in Sudan rests not on the release of the hybrid *per se*, but rather on key issues raised, problems anticipated, decisions made, and efforts undertaken in making the fruits of this technology be available to the farmers of Sudan.

Among the issues considered, the following contributed significantly to the wide adoption and use of Hageen Dura-1: First, recognizing that this was the first time a hybrid variety had been released and that the expertise for production, processing, certification, and marketing of hybrids did not exist in Sudan, the formation of a National Advisory Committee was suggested to monitor the adoption of hybrid seed. Second, a Pilot Project document was prepared which outlined a plan for careful hybrid sorghum seed production schedule involving public and private organizations in the country. Third, an aggressive farmer education program on the use of hybrid seed and associated inputs was embarked upon. Fourth, a successful international workshop that initiated dialogue and action on establishing a viable hybrid sorghum seed industry in Sudan was planned and organised.

Current Interest in Hageen Dura-1

Interest and enthusiasm about Hageen Dura-1 by farmers, seed entrepreneurs, research scientists, administrators, and government officials in Sudan has exceeded any initial expectation. Demand for Hageen Dura-1 far exceeds available seed supply. As a result the United States Agency for International Development, in addition to encouraging and supporting increased seed multiplication by the Pilot Project in Sudan, arranged for offshore production and delivery of over 1000 metric tons of Hageen Dura-1 seed by US seed firms by May 1986. During the 1985 crop season, only 2 years from the release date, Hageen Dura-1 was planted on over 70,000 acres (Table 7). The total Hageen Dura-1 seed supply targeted for the 1986 crop season (external contracts plus domestic production) will plant over 600,000 acres (Table 7).

While experimental yield testing over 4 crop seasons (1979-1982) reported a yield superiority of 50% over open pollinated improved varieties, large

Table 6. Seed Yield (kg/acre) of Experimental Seed Production Testing of 3 Promising Elite Experimental Hybrids and their Female Parent – GRS Farm (1982).

Seed Field	Pedigree	Seed Yield (kg/acre)*
EEH-1	TX 623A x Su. Cr. 54: 18/17	1922
EEH-2	TX 623A x Su. Cr. 36: 80/70	1529
EEH-3	TX 623A x Karper 1597	1753
A x B	TX 623A x TX 623B	2294

* Planting arrangement used was 2:4 i.e. 2 rows of pollen parent and 4 rows of seed parent. The recorded yield is, therefore, on 2/3 of an acre.

scale on-farm trials have yielded even more significant results. Under farmers' conditions a 2- to 4-fold yield increase over traditional sorghum varieties was reported. According to a recent USAID document, in 1984, a year of severe drought in Sudan, Hageen Dura-1 under rainfed conditions produced yields that were about 85% higher than local varieties. In the irrigated areas, the yields were about 300-400% higher than longtime average yields of local varieties. The suitability of Hageen Dura-1 for both the rainfed and irrigated sectors of Sudan was also reaffirmed through these on-farm trials. Again in 1984, in the Damazine area, under only 380 mm rainfall, a 70 acre field of Hageen Dura-1 averaged 400 kg/acre where many surrounding fields of local varieties produced no heads. In 1985 the growing conditions were more favorable for sorghum production and Hageen Dura-1 maintained yield superiority of 2 to 3 fold over local varieties in both rainfed and irrigated conditions.

Creation of a Seed Industry

One of the significant spinoffs of the hybrid sorghum research in Sudan has been the development of an infant seed industry in the country. The production of hybrid sorghum seed has grown from 3 metric tons in 1983 to an estimated 1500 metric tons in 1985 (Table 8). Of the total seed

Table 7. Growth in use of hybrid sorghum in the Sudan (1983-1986).

Year	Hybrid Seed Available	Hybrid Area Planted	Grain Produced	Estimated Increase in Gross Value Benefit Due to Use of Hybrid Seed	
	MT	Acres	MT	Prod MT	Dollars
1983	3	-	-	-	-
1984	25	6,250	9,375	6,250	781,250
1985	294	73,500	110,250	73,500	9,187,500
1986	2,500	(625,000)*	(937,500)	(625,000)	(78,125,000)

* Projected

Table 8. Area under Hageen Dura-1 seed production (acres; 1983-1986).

Year	Pilot Project Target			Actual		
	Public	Private	Total	Public	Private	Total
1983	1	-	1	1	-	-
1984	165	15	180	600	50	650
1985	380	75	455	1,340	1,350	2,690
1986	775	225	1,000	?	?	?

production from 2700 acres in 1985 approximately 50% of the planting was done by 12 newly established private seed companies. In 1983 no such company existed or operated in the country. The investments and participation in seed production indicate an increasing interest and awareness of the potential of hybrid sorghum in a growing agro-industry in the Sudan.

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10 Sorghum Improvement for the Moisture-stress Regions of Ethiopia

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Abstract Though sorghum (*Sorghum bicolor* L. Moench) is grown in most regions of Ethiopia, our priority areas on sorghum improvement are the lowlands where rainfall is unreliable and erratic and crop failures are common. There are no criteria for selecting drought tolerant types, but desirable factors that help production under moisture stress include stand establishment, variety and hybrid development and performance evaluation in dry environments.

Results indicate the existence of variability in emergence. Efforts at varietal development, through use of local and introduced germplasm and hybridization with *in situ* evaluation in moisture stress areas have resulted in some useful hybrids and varieties adapted to dry areas. Hybrids have been found better suited than varieties to such stress environments as a result of earliness, better adaptation and stability. Variety on hybrid development would need to be complemented by agronomic technologies that would conserve moisture and improve water use.

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is a dominant food cereal grown in most cropping regions of Ethiopia. It is grown in the high, intermediate and low elevation regions of the country, and is particularly important in the lowlands of Ethiopia where rainfall is unreliable and erratic and crop failures are common. The lowlands have been affected by recurrent droughts for many years. National yield levels are below 1 ton/ha and the crop suffers very much from weather conditions and pests. The approaches used in breeding sorghum for moisture stress zones in Ethiopia and areas of emphasis are presented in Table 1.

Ethiopia is comprised of an interior plateau surrounded by coastal lowlands. The arid and semi-arid areas (dry and thorn savanna) have low

Table 1 Approaches used in breeding sorghum for moisture stress zones of Ethiopia.

1. Acquisition/generation of variability
   - local and introduced germplasm
   - hybridization (varietal crosses, F_1 hybrids)
2. Evaluation and selection
   - screening for useful traits
   - pedigree system (segregating generations)
3. Performance tests
   - yield trials
   - stability analysis

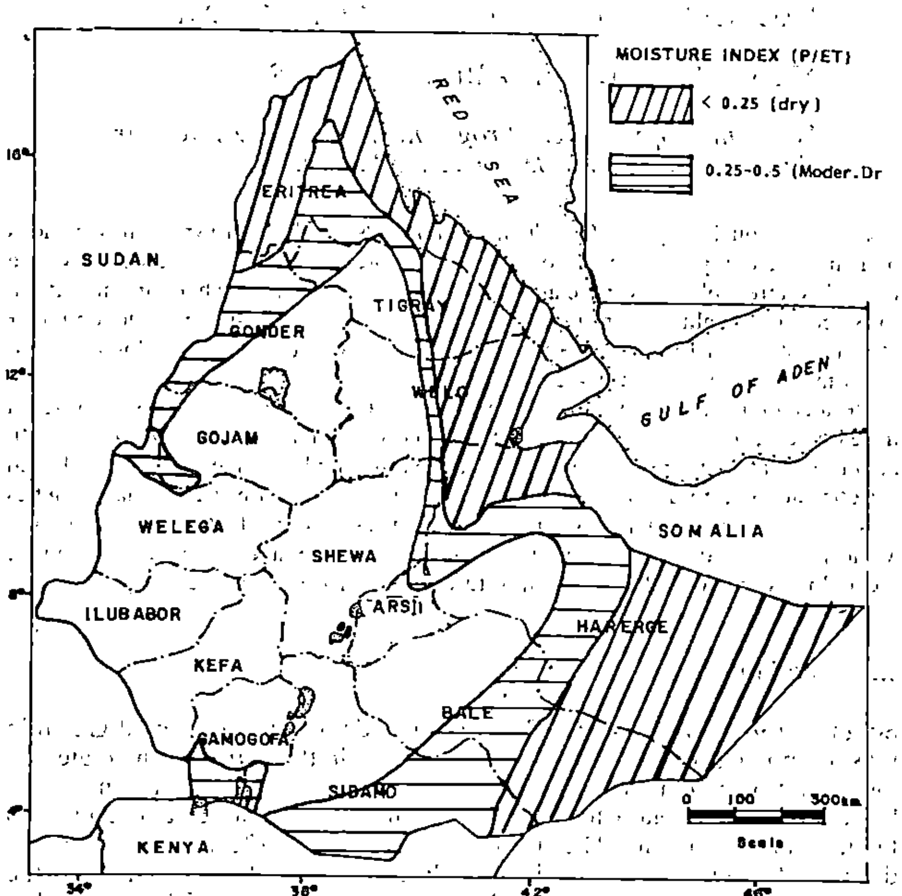

Figure 1. Map of Ethiopia showing the arid and semi-arid regions (adapted from met. maps of Ethiopia P4)

altitudes and are more extensive in the southern, south-eastern and north-eastern Ethiopia (Fig. 1). About 50% (611,000 km^2) of the land area could be classified as semi-arid (Troll, 1966). Furthermore, due to low precipitation and high temperature these areas are characterized by water deficits thus the period available for crop growth is reduced (see Daniel Gamachu, 1977).

For research on sorghum improvement in Ethiopia four major classes of adaptation have been established for carrying out breeding and selection work at selected locations representing each adaptation class.

This paper reviews the work on sorghum breeding (improvement) in Ethiopia with reference to moisture stress areas. Desirable factors that help in optimizing production under moisture stress, include stand establishment, varietal development and performance evaluation in dry sites and years.

Stand Establishment

Experience in Ethiopia indicates that stand establishment is a serious problem especially in moisture stress areas, and is an important component

Table 2 Adaptation classes for sorghum breeding in selection in Ethiopia

Adaptation Class	Elevation (m)	Length of growing period (days)
I. High	1900	170 to 200
II. Intermediate	1600 to 1900	150 to 180
III. Low	1000 to 1600	91 to 130
IV. Very low	<1000	<90

for obtaining optimum yields. All the benefit from management inputs can only be realized with a full stand. Apart from agronomic technologies that ensure good stands, the importance of the inherent ability of varieties for better emergence has been a subject of investigation (Peacock, 1979, Soman *et al.,* 1984). Faster germination and better establishment would help in drought avoidance and further optimize yields.

In the Ethiopian sorghum program, investigations into identifying genotypes with good establishment have provided information on the existence of genotypic variation in field emergence in the materials evaluated.

One hundred sorghum lines were tested for field emergence in a 10 by 10 triple lattice under irrigated and rainfed conditions. One hundred seeds from each variety taken at random were treated with fungicide and planted at a depth of 4 cm. Emerging plants were recorded after 10 days. The percentage emergence of selected lines are presented in Table 3. Although there was a high percentage germination in the laboratory of the lines used, the range in percent emergence under irrigated and rainfed conditions was in the order of 14% to 83%. The first three lines had higher field emergence compared to the rest. Emergence was not related to seed weight ($r = 0.124$, $n = 94$) or to the type of endosperm. These results thus indicate the

Table 3 Germination, emergence percentages and one hundred seed weight of some selected entries showing good and poor field emergence (n = 94)

Pedigree	Laboratory germination %	Field emergence %		Seed weight (g/100)
		rainfed	irrigated	
78HR 133-135	100	83	74	2.69
82 LPYT-1#3	99	83	78	1.92
SAFRA	98	82	72	4.51
A-2045	95	34	29	2.32
M-90362	88	31	37	2.89
84MW 4094	87	27	18	1.87
Max.	100	83	82	4.51
Min.	80	14	18	1.42
Mean	94	60	54	2.58
S.E±	3	6	6	0.13
CV (%)	5	19	18	9

existence of genetic variability for field emergence, and the need for continuous evaluation of breeding lines for field emergence and overall performance under moisture stress.

Variety and Hybrid Development

Examination of the rainfall pattern and distribution in the semi-arid areas of Ethiopia reveals that the length of the growing period may not exceed 90 to 100 days (Henricksen and Durkin, 1985). Farmers who are used to planting long duration and tall varieties unsuited for the area have experienced crop losses in recent years. It therefore became necessary to develop early maturing varieties and hybrids which could mature in the late June to October period, which are the months of highest and reliable rainfall for most parts of Ethiopia. The objective is to develop varieties/hybrids that flower in less than 70 to 75 days instead of flowering over 125 days in the local cultivars. The yield levels of the short duration varieties may not be at the level of the traditional and late season types in years of optimum rainfall, but yields are satisfactory at all seasons. Varietal development has been through introduced and indigenous germplasm evaluation and hybridization.

Indigenous collections

The Ethiopian sorghum germplasm collection representing nearly 5,000 accessions had been evaluated for several agronomic characteristics, including days to flowering (Brhane and Yilma, 1978). Entries that flowered in 80 days or less comprised less than 2% of the entire collection while over 50% of the collection flowered in more than 100 days (Table 4). Despite this, a local entry Gambella 1107 had been identified and has done remarkably well in low elevation sorghum producing areas. To widen the germplasm base, alternate sources of desired variability had to be looked

Table 4 Distribution of days to flowering of Ethiopian sorghum germplasm collections grown at Alemaya and Asebot, 1978

	Percent of total collections at	
Class (days)	Alemaya	Asebot
60 to 70	0.2	0.2
71 " 80	1.2	0.2
81 " 90	6.1	1.1
91 " 100	17.6	27.4
101 " 110	21.8	28.8
111 " 120	13.3	20.0
121 " 130	14.5	14.2
131 " 140	12.1	4.6
>140	13.2	3.5
	n=4616	n=4020

into elsewhere. Consequently, our program established contacts with international institutes and national programs dealing with sorghum improvement.

Introduced germplasm

Many potentially valuable materials in the form of lines varieties, hybrids, seed and pollinator parents and populations received from foreign sources were evaluated from 1976 to 1985 (Table 5). A large number of material tracing to national and international programs have been planted and screened in moisture-stress areas and some have been found useful. Some introductions initially advanced were less than 11% considering all sources; less than 5% were finally included in replicated varietal trials or used as parents in the crossing programs (Brhane, 1981).

Several promising introduced materials have been identified from various yield trials in various years and dryland locations. (Brhane and Yilma, 1978; Brhane and Abebe, 1980). Three early maturing and low elevation adapted varieties namely Kobomash 76, $76T_1$ #23 and Melkamash 79 released for production were derived from introductions. Some others are nearing release pending final verification.

In general, there has been a progressive decline in the amount of material received from foreign sources over the period, 1976 to 1985 as the Ethiopian program had matured and generated the necessary base material through hybridization.

Hybridization

In this program, local and introduced lines with low elevation adaptation were identified every year and intercrossed in order to combine desirable traits needed for production in the drought-prone and sorghum producing zones of Ethiopia. Every year, several hundred hand emasculated crosses are made. Selfing and screening for several generations until stable and homozygous lines are obtained and carried out using off-season and representative production sites.

The pedigree method has been used in handling segregating generations at the various sites. The system of handling advanced breeding lines and

Table 5 Summary of introduced sorghums planted and initially advanced in moisture stress locations by the Ethiopian sorghum program, 1976 to 1985

	Total number of introductions	
Source	Planted	Initially advanced
International Centers	15,581	1688
ALAD, FAO, ICRISAT		
SAFGRAD	822	62
National Programs		
India, Kenya		
Sudan, Tanzania,		
Uganda, USA.		

segregating generations has been elaborated in ESIP's Progress Reports (Brhane and Yilma, 1978).

A summary of the number of grow outs and initial selections from segregating generations planted at moisture stressed sites over the past 10 years is presented in Table 6. As shown in the table, an average of 860 populations were grown each year. Each population was grown in at least three sites and every season selections from each generation at the different testing sites are pooled to form the planting material for the following season. Since 1980, these materials have become a major source of entries for different preliminary and national yield trials at low elevation location. Some lines, namely 81ESIP4, 81ESIP7, 81ESIP17 and 81ESIP21 are in the final evaluation stage.

In addition, based on the cumulative experience of other sorghum workers elsewhere, a modest hybrid program had been initiated to identify high yielding sorghum hybrids for the moisture-stress zones (Brhane, 1980). Hybrid sorghum results in higher grain yields compared to varieties even under stress environments (Doggett, 1970).

Since 1977, over 200 seed parents, about 500 pollinator lines and the resulting 4,000 hybrids have been screened for *per se* and hybrid performance. The earliness of these hybrids has been of great advantage in conferring reliability in sorghum production in moisture-stress areas compared to currently available varieties. Seed production problems notwithstanding, our program has identified early and stable hybrids for use in such areas (Abebe *et al.*, 1984).

Performance Tests

The high yields of some of the varieties and hybrids that have been developed may be partly due to their inherent yield potential rather than drought resistance *per se*. However, some varieties and hybrids that had been included in tests across locations and years have consistently resulted in acceptable yield levels in some drought susceptible zones.

A comparison of performance of some recommended varieties and near release varieties is presented in Table 7. The data is from 14 environments (year x locations) and considerable variation was recorded as indicated by the range in yield, flowering days and plant height. The earliest variety currently recommended is $76T_1$ #23. Two new varieties 81ESIP40 and 81ESIP47 with similar maturity as $76T_1$ #23 have produced higher yields in the same environments. Again 81ESIP7 with comparable flowering as

Table 6 Summary of selections from breeding nurseries (F_2 to F_4) evaluated at some moisture stress location of Ethiopia, 1976 to 1985

Evaluation sites	F_2		F_3		F_4	
	grown	selected	grown	selected	grown	selected
AT, DK, HU KB, MI, MK	8608	1861	4202	934	4527	277

AT – Asebot, DK – Dakata, HU – Humeria, KB – Kobo, MI – Mieso, MK – Melkassa

Table 7 Comparison of mean grain yield, days to flowering and plant heights of varieties proposed for release (top three) and already released (bottom three) for moisture stress regions (m = 14).

Variety	Grain yield q/ha		Days to flower		Plant ht. cm	
	Range	Mean	Range	Mean	Range	Mean
81 ESIP7	8-59	25	70-104	83	97-137	112
81 ESIP40	5-43	24	66-101	79	95-150	116
81 ESIP47	6-38	21	63-104	77	99-174	140
Gambella 1107	4-46	21	74-98	84	110-170	141
Melkamash 79	5-55	22	71-101	83	103-166	140
$76T_1$ no. 23	6-41	17	59-111	79	101-150	123

Table 8 Comparison of mean grain yield, environmental response (b), days to flowering and plant height of selected hybrids and varieties grown at moisture stress sites.

Entry	Grain yield q/ha					
	n	Entry mean	Site mean	b	r^2	Flowering days
IS10468xBulk Y-3	6	33	25 ± 18⁺	1.01 ± 0.09@	0.97	65
" xYE 159	6	29	25 ± 18	1.11 ± 0.15	0.96	65
Tx622AxYE294	6	28	25 ± 18	1.03 ± 0.14	0.93	65
IS1036AxYE96	11	28	23 ± 14	1.14 ± 0.20	0.79	66
Kobomash 76	12	18	28 ± 20	0.58 ± 0.08*	0.84	70
Melkamash 79	13	15	20 ± 14	0.81 ± 0.10	0.86	76
Gambella 1107	8	14	20 ± 11	8.77 ± 0.19	0.76	80

n – number of environments; +, @ – std. dev. of mean and b, respectively; * – sig. diff. from unity.

Melkamash 79 and Gambella 1107, nevertheless gave higher yields. These varieties all are suited to Adaptation Class III, where our objective is to maintain the maturity cycles and increase yield or if possible, maintain yield levels and reduce the maturity cycle to fit into Adaptation Class IV.

Thus, hybrids were also tested in moisture stress areas in comparison with varietal checks (Table 8). There were a variable number of environments in which the tests were undertaken for each of the entries. Results indicate that all hybrids were earlier than the varieties and produced superior yields. Moreover, hybrids showed better adaptation to these areas as indicated by higher entry mean compared to the site mean. Hybrids exhibited better stability (b values close to unity), but varieties had regression coefficients less than 1.0 indicating their failure to respond to better environments. More of the variation (79-97%) in mean yield of hybrids was explained by the variation in location mean as compared to varieties. This suggested that hybrids with their high r^2 values had better predictable performance than varieties.

In summary, the better hybrids were identified by considering earliness, adaptation, stability and yield advantage when tested across diverse environments represennting moisture-stress conditions.

Future Plans

Under moisture-stress conditions, great potential pay-offs in optimizing yields would be realized through development of genotypes that withstand drought and by altering the plant environment to increase the availability of stored moisture.

Sorghum genotypic differences to water stress exist (Blum, 1974; Sullivan & Eastin 1974). Escape and stability mechanisms may not be sufficient for crop production in moisture-stress environments and therefore directed selection for tolerance/resistance will be initiated and will focus on specific adaptation traits for moisture stress. The line-source has been reported to be useful for screening sorghum genotypes for drought resistance through maintenance of a stress gradient (O'Neill et al., 1983). There will be a need for looking further into improved stand establishment, seed size, seed set and test weight under moisture-stress. Redefinition of moisture stress and sorghum producing areas into agronomically useful classes will be continued in order to improve on evaluations.

Moreover, enhanced studies on various tillage methods, moisture conservation systems, and agronomic practices suitable for moisture-stress locations would complement the varieties to be grown in such environments.

The responsibility for innovations that forestall possible calamities in terms of crop failure due to stress rests on all disciplines of agriculture. Varietal development is just a single component of the dryland production system, thus an integrated approach whereby variety development will be combined with crop husbandry, soil and water conservation, reafforestation and livestock production will need to be developed.

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11 Sorghum Improvement and Production in Eastern Africa

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Abstract Sorghum is the most important and staple cereal in the semi-arid parts of eastern Africa. The leading improved varieties available for the various ecological zones of the region are ETS 2752, Bakomash 80, Gambella 1107, Serena, Seredo, Dabar, and Tegemeo. Only one hybrid, Hageen Durra-1 of the Sudan, is in current commercial production in the region. Under low rainfall conditions it is essential to use water harvesting and conserving techniques for the crop at critical times. Of all the weeds of sorghum in eastern Africa, *Striga hermonthica* is the most serious and economically of the greatest importance. *Striga* resistant varieties tried in the region are IS 9830, Tetron, Framida, N13, SPV 103, 12610C, Dobbs and Serena. Among the diseases under dryland moisture stress situations, charcoal rot is the most serious disease in the region. Stem borers are the most serious group of insects damaging sorghum in eastern Africa. Birds, particularly *Quelea*, are often the first factor restricting the spread of a good variety with good grain quality. Drought is a major problem limiting sorghum production in the region.

Cooperative regional sorghum improvement has been facilitated by the SAFGRAD/ICRISAT program through regional trials and nurseries, introduction of germplasm, organizing workshops, and advising the national programs of the region. Through the regional trials and nurseries it has been possible to identify elite varieties for the various national programs of the region. The lack of good national seed industries in the region limits the promotion of promising varieties. Networking model is the best approach to strengthen and expand the regional sorghum improvement activities of eastern Africa.

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is the most important cereal in the semi-arid parts of the eastern African region comprising Kenya, Uganda, Tanzania, Sudan, Ethiopia, Somalia, Burundi, and Rwanda. These countries collectively produce about 4 million tons of sorghum grain in just over 6 million ha of land giving a regional mean yield of only about 600 kg/ha compared to a world average of about 1500 kg/ha (Table 1). The Sudan alone has over 50% of the sorghum area although it has the lowest national mean yield in the region. The four countries with the largest hectarage in the region, namely Sudan, Ethiopia, Tanzania, and Somalia account for almost 90% of the eastern Africa sorghum area.

For most of the countries in this region, the crop is the traditional staple for the native population. Since sorghum is indigenous to this part of Africa, the genetic diversity of the crop in the region is wide (Doggett, 1970; Gebrekidan, 1979; Mann *et al.*, 1983). The major use of the crop in the region is for food although it is also widely used for beverages, feed, fuel and construction.

Almost all the major sorghum ecological zones found worldwide are present in eastern Africa. In the 1982 regional workshop held in Ethiopia, sorghum workers of eastern Africa recognized four major sorghum

Table 1 Sorghum production statistics for 1984*

Producers	Area harvested (1000 ha)	Yield (kg/ha)	Production (1000 tons)
Burundi	177	847	150
Ethiopia	837	1,039	870
Kenya	145	1,034	150
Rwanda	180	1,111	200
Somalia	470	500	235
Sudan	3,500	414	1,450
Tanzania	650	692	450
Uganda	230	2,043	470
Eastern Africa	6,189	642	3,975
All-Africa	15,328	587	9,002
World	49,004	1,463	71,698

* Source: FAO Production Year Book Vol. 38. 1985. FAO, Rome.

adaptation zones in eastern Africa; these are, high elevation (above 1800 m), intermediate elevation (1500 – 1800 m), low elevation (below 1500 m), and very dry lowlands (below 1500 m altitude and 1500 mm annual rainfall) (Gebrekidan, 1982a). High and intermediate altitude sorghums are most important in Ethiopia, Rwanda, Burundi, and Uganda whereas lowland sorghums are grown and important throughout the region. Sorghums of the very dry lowlands are of special interest to the Sudan, Ethiopia, Somalia and Kenya.

Traditional Practices

Sorghum production practices in this region are ancient and have not changed much for centuries. Hoe cultivation is widespread although animal drawn ploughs are traditionally used in Ethiopia. Sorghum is grown mostly under subsistence conditions by small peasant farms throughout the region except in parts of the Sudan where large scale mechanized farms are common. Under subsistence conditions, the crop is broadcast often in mixtures with other crops. Most farm operations from planting to harvesting are done manually using family labor. There is very little use of improved seeds, fertilizers, crop protection chemicals, and improved tools by the average peasant sorghum farmer of eastern Africa. The traditional sorghums grown in the region take three to nine months to mature depending on the amount and distribution of rainfall and altitude. The local sorghums are often tall and late maturing.

Varietal Improvement

Sorghum varietal improvement work in eastern Africa started at modest levels about the same period in the early 1950s in the Sudan, Ethiopia, and the former East African Community (Nour, 1984; Gebrekidan, 1982b;

Doggett, 1986). Sorghum research in Rwanda and Burundi seems to have started even earlier. The released or most promising varieties available for the three most important sorghum ecological zones of eastern Africa are given in Table 2.

The breeding methods used in the region to develop the varieties listed in Table 2 have been selection from local collections and introductions (mostly within the region), and pedigree selection within planned crosses. In each of the national sorghum improvement programs of eastern Africa, the emphasis has been and continues to be on the use of conventional and traditional breeding methods, with the concentration of work on local collections and introductions. Currently, the programs which have substantial amount of hybridization work are those of the Sudan, Ethiopia, Uganda, and Tanzania. Crossing has involved both indigenous and exotic

Table 2 Released and promising sorghum varieties of the eastern Africa region by ecological zone.

	High Elevation, > 1800 m	Intermediate Elevation, 1500-1800 m	Low Elevation, < 1500 m
Burundi		SVR 8 SVR 157	5DX 160
Ethiopia	ETS 2752 Alemaya 70	ESIP-11 ESIP-12 Bakomash-80	Gambella 1107 Melkamash 79 Kobomash 76 76 T1-23 Serena
Kenya	E-1291		2KX 17 76T1-23 Serena Seredo Dobbs
Rwanda	BM 10 BM 27	SVR 157 Ikinyaruka WS 1297 Susa	Badege Urimimbi
Somalia			Elmi Jana Baidoa Local
Sudan			Gadamel Hamam Dabar Cross 35:5
Tanzania			Tegemeo 2KX 17/6 2 KX 89
Uganda			Serena Seredo 2KX 17/B/1 4MX 11/10
Total No. of varieties	5	8	19

germplasm as parents. Hand emasculation has been widely used except at Serere, Uganda where hot water emasculation is an established procedure. Off-season operations for making crosses and/or advancing generations are the main features of the breeding programs of these countries. Evaluations of segregating generations and advanced lines have been done in locations which are representative of the target production ecological zone.

Development of Hybrids

Three countries in the region which have significant work on hybrid sorghum are Uganda, Ethiopia, and the Sudan. Currently only the Sudan and Ethiopia seem to be maintaining the momentum on hybrid sorghum research. Hybrid sorghum work in all the three countries has been and continues to be for the low elevation zones only.

Hybrid sorghum generally give higher yields than local varieties under optimum and stress environments. The percentage of grain yield increase of hybrids over local varieties is higher under stress indicating the superiority of hybrids in yields and stability across environments (Rana *et al.*, 1972; Doggett, 1970).

The hybrid sorghum work at Serere, Uganda appears to be the oldest program in the region starting from the early sixties, Doggett (1970). Records of Research in the annual reports of the former East African Community also describe this work in detail. The Ugandan hybrid program has been based mainly on CK60A as the male sterile parent. The recommended hybrids include Hijak (CK60A × SB65), Hibred (CK60A × Simila) and Himidi (CK60A × Lulu) (EAAFRO, n.d.). Male sterile lines locally developed at Serere, Kafinum A and 7DMS 7A were reported to be more promising than CK60A (Mukuru *et al.*, 1976). There is currently no large scale production of hybrid sorghum in Uganda.

The Ethiopian hybrid sorghum work was initiated in the mid-seventies (Gebrekidan, 1980). The female parents used in the most promising hybrids of the Ethiopian program were IS 10360A, IS 10468A, P954066A, Tx622A, and Tx623A. The best pollinators used were mostly yellow endosperm lines selected from Karper's nursery of Texas. The best hybrids are those with IS 10360A as the female parent and YE 96, YE 121 Tx 430, and Bulk Y-3 as the pollinators. The mean grain yields of the top yielding hybrids over three years of testing at Melkasa, Ethiopia was 5300 kg/ha compared to 2900 kg/ha for the check variety, Kobomash 76.

Although the advantages of hybrid sorghums have been demonstrated clearly at least in the Melkasa area of Ethiopia, there is to date no large scale production of hybrid sorghum in Ethiopia. Hybrid sorghum work in Ethiopia still continues at the research stations.

Sudan is the only country in the region which has moved hybrid sorghum from the research station to large scale seed and grain production. Hybrid sorghum was the sole topic for the special workshop held in Wad Medani, Sudan in 1983. In that workshop, Gebisa Ejeta (1983) described the details of the hybrid sorghum work of the Sudan. In 1983 the first Sudanese sorghum hybrid, Hageen Durra-1 (Tx623A × Karper 1697), was recommended for release. Hageen Durra-1 has given about 150% of the yield of the local variety both under irrigated and rainfed conditions. Under irrigated experimental conditions, the hybrid produced about 5,000 kg/ha whereas under rainfed situations its yields have been about 3,000 kg/ha. Currently, Hageen Durra-1 is under large scale production involving cooperative arrangements between the Agricultural Research Corporation, the Sudan Gezira Scheme, and the National Seed Administration. The seed has been distributed to the irrigated and rainfed schemes of the Sudan. In the Sudan program the most widely used male sterile line has been Tx 623A.

Population Improvement

Only two national programs namely Uganda and Ethiopia conduct some work on sorghum population improvement.

In the Ugandan program, the various populations were formed with the use of the ms_3 genetic male sterile stock for random mating. The selection methods used were female choice, alternating female choice and selfed plant, and S_1 testing (Doggett, 1972). The populations developed at Serere have contributed to the population improvement work of ICRISAT. In Uganda itself there does not seem to be any released or advanced lines tracing to the population improvement work.

In Ethiopia, population improvement work has been based on the ms_3 gene and the dented seed physical character of the high lysine Ethiopian lines. The ms_3 stock has been used to facilitate random mating and selection has followed S_1 testing. With the dented seed character as a marker selection has been based on modified half-sib and S_1 selection. Selections from this scheme have been advanced to yield trials.

Varieties Grown in the Region

Although over 30 varieties and improved lines have been mentioned under the varietal improvement section above, only a few of these are under large scale production in the region. Well over 90% of the sorghum production in eastern Africa is still under traditional local varieties which display tremendous genetic diversity. The majority of the farmers of the region save their own seed of these local varieties for production under subsistence conditions.

The leading improved varieties which are mostly grown in the lowlands under large scale production are Serena, Seredo, Gambella 1107, Dabar, Tegemeo, 76T1-23, and Bakomash 80. Seeds of these varieties are often available with the recognized national seed producers of each country.

Cultural Practices

Sorghum production practices in the region are mostly traditional under rainfed conditions. The only major area where sorghum is grown under organized large scale irrigated conditions is the Gezira scheme of the Sudan. In the traditional culture, sorghum is usually planted in mixtures with maize or legumes, or is grown continuously without rotation. Broadcasting is a standard practice and very little fertilizer is used; weed control is often done late.

Based on a sorghum management trial with short and early maturing varieties under lowland conditions conducted in Tanzania for three years and four locations, a plant density of 160,000 plants/ha and 60 kg N/ha with the first weeding done two weeks after planting followed by a second weeding done at 45 days after planting was the recommended practice (Mushi, 1984). At a highland situation in Arsi Negelie, Ethiopia, with a tall and late cultivar, a plant population of 160,000 plants/ha also gave the highest grain yield (6 tons/ha) (Kebede and Menkir, 1984). Under dryland and moisture stress situations such as those of Karamoja, Uganda, the recommended plant population was about 60,000 plants per ha (Rowlands, 1986). With reduced effective rainfall and lower soil fertility situations the plant density should be progressively lower.

Under all of these conditions, it is essential to plant early and control weeds satisfactorily, particularly in the early stages of the crop. Crop rotation and the use of farmyard manure, when available, are good recommended crop production practices. Under low rainfall conditions, it is essential to use water harvesting and conserving techniques for the crop at critical times.

The use of fertilizers is economical only if water for crop growth is not limiting. In very dry situations with limited rainfall, applying fertilizer is often risky and uneconomical. In the eastern Africa region nitrogen and phosphorus are the most needed fertilizer elements.

Striga and other weeds

Since the sorghum crop is a slow starter it is a poor competitor with weeds which deprive the crop of its water, nutrient, and light requirements. Weed control by small scale farmers is mainly done manually. Very limited use of herbicides for the control of weeds in the region is practised.

Of all the weeds of sorghum in eastern Africa, *Striga hermonthica* is the most serious and of the greatest economic importance. The germination and establishment of *Striga* requires the presence of a suitable host plant that produces the necessary root chemical exudates for the stimulation of germination. Typically sorghum produces such exudates and is a good host for establishment and development of the parasite.

Ogborn (1984) listed and discussed a number of techniques available to small holders for the control of *Striga*. These include hand pulling, resistant varieties, genetic immunity, evasive immunity, tolerant varieties, trap-cropping, crop rotation, soil active herbicides, strigol analogues, ethylene injection, ethepon application, extra nitrogen fertilization, foliar active herbicides, and biological control. The severity and expansion of *Striga* into new areas in eastern Africa appears to be increasing. Every year, more land is also made unsuitable for sorghum cultivation because of heavy *Striga* infestation.

Although the use of resistant or tolerant varieties is considered the simplest and most economical method of *Striga* control, this method would be more effective if it is used in combination with other methods of the control of *Striga*. Sorghum varieties for eastern Africa which are resistant to *Striga* include IS 9830, Tetron, Framida, N13, SPV 103, 12610C and Entry 39 (Ramaiah, 1984). Dobbs and Serena are also recognized as *Striga* resistant in East Africa. Most varieties with good levels of *Striga* resistance are usually not in the best agronomic backgrounds. It is, therefore, necessary to have vigorous breeding programs with special emphasis on *Striga* so that agronomically elite *Striga* resistant/tolerant varieties could be developed for the region. Currently the national programs in the region which have some *Striga* research underway are those of Kenya, Ethiopia, and the Sudan. *Striga* research in the Sudan has been described by Khidir

(1983) and that of Ethiopia has also been reported on by Teferedegn and Fessehaie (1982).

Diseases and Insects

A wide range of sorghum diseases occur in east Africa. If a susceptible host variety is grown under an environment conducive to good disease development, some of the diseases could account for substantial yield losses. Among the major sorghum diseases in the region are smuts, grain molds, sugary disease, charcoal rot, anthracnose, leaf blight, rust, bacterial streak and stripe. The local varieties grown in each area are generally tolerant to the prevalent diseases. Since the breeding programs in the region screen and evaluate breeding materials under natural pressure of the diseases, materials advanced often possess good levels of disease tolerance or resistance.

Under dryland and moisture stress situations, charcoal rot (*Macrophomina phaseolina*) could be severe. The varieties recommended for the lowland dryland environments of eastern Africa do not carry sufficient levels of charcoal rot resistance. Greater effort is needed in charcoal rot resistance breeding for the dry lowlands of eastern Africa.

Insect pests are major yield reducers in eastern Africa. The important group of insects of sorghum in the region are those of seedling, foliage, stem, and storage. The major pests are shootfly, armyworms, stem borers, grain weevils and moths. The use of resistant varieties is an important method of reducing losses due to insects. The status of breeding sorghum for resistance to insects in eastern Africa has been reviewed recently (Gebrekidan, 1985). There are a wide range of sources of resistance for insects. Stem borers are the most serious group of insects damaging sorghum in eastern Africa and concerted efforts are needed in breeding for resistance to these pests. An effective insect resistance breeding work requires close collaboration between the breeder and the entomologist.

Birds

Birds, particularly *Quelea quelea*, are perhaps the number one crop protection problem of sorghum in the low to intermediate altitude zones of eastern Africa. Within the limits of ecological adaptation, birds are often the first factor restricting the spread of a good variety with a good grain quality. Very often, in areas which are marginal for maize but excellent for sorghum farmers prefer to plant maize to avoid the bird problem although they are aware of the high probability of the failure of the maize crop. Where sorghums are grown under heavy bird pressure, the types grown are brown and high in tannin which normally are not considered good grains for most traditional food products. It is also well established that the high tannin grains are associated with poor protein content.

Sorghums with different morphological characteristics such as goosenecks, compact or loose panicles, large glumes and long awns have been tried as methods of reducing bird damage. Under high bird pressure none of these seems to work. Although nutritional quality is a problem, the high tannin and astringent tasting grains appear to be the most effective plant characteristics useful in reducing bird losses.

It is not possible to solve the bird problem in sorghum through plant breeding methods alone. Concerted effort has to be made to control the birds, particularly *Quelea*, through other crop protection means. Elliot (1986) has given a good overview of the *Quelea* control strategies. The establishment of the *Quelea* unit within the Desert Locust Control Organization of eastern Africa is a step in the right direction.

Drought

In the semi-arid zones of eastern Africa the predominant factor that limits sorghum production is shortage of moisture. However, under rainfed conditions where the rains are short and erratic, as they normally are in most of semi-arid eastern Africa, it is often not economical for the small scale farmer to control and provide water for sorghum production. Under such situations the most practical method for the farmer is to adopt drought resistant/tolerant cultivars along with conservation and use of his available soil and water resources to the best advantage of his crop.

Cultivars which are suitable for production under drought-prone conditions may possess any one or combinations of the mechanisms of drought escape, avoidance, tolerance, and recovery resistance. Drought escape is characteristic of early maturing varieties. The varieties traditionally grown under short and erratic rainfalls are normally early. Farmers of such areas have high demand for early varieties. In plant breeding, the development of early maturing and high yielding varieties for drought situations is a difficult job because of the negative correlation between earliness and high yield. Considering the other mechanisms for stabilizing and optimizing yield under drought (avoidance, tolerance, and recovery resistance) selections done under natural conditions are associated with very high coefficients of variation which often make the whole exercise difficult and frustrating. It is therefore necessary to develop effective and reliable screening techniques for drought resistance breeding.

The genetic variability for drought escape/resistance/tolerance available in the indigenous eastern Africa sorghums is quite good and large. The dura race which is native to and common in eastern Africa is among sorghums which are most suitable for drought. More plant breeding work in eastern Africa is needed on this characteristic of the duras of the region. More pointed germplasm collection of the duras of eastern Africa in the low and erratic rainfall zones can be very useful for an expanded sorghum drought resistance breeding for the region.

The leading improved varieties which are currently grown under drought conditions of the region are lowland ones and include Serena, Sedo, Tegemeo, Debar, and Gambella 1107. However, local cultivars cover most of the dryland sorghum area of the region.

Regional Cooperation

Before the collapse of the East African Community (EAC) in 1977, regional cooperation in sorghum improvement in East Africa used to be coordinated from the regional base at Serere, Uganda. A number of stations and testing sites in the East African countries participated in growing trials and nurseries.

To promote regional cooperation, since late 1982 SAFGRAD and ICRISAT initiated an eastern African regional network for the improvement of sorghums and millets. The main objectives of the regional network are: (a) to organize operational sorghum regional trials (b) to assist the national programs in the conduct and evaluation of the trials (c) to introduce and evaluate germplasm from outside the region and make those promising germplasm introductions to the national programs of the region (d) to consult and advise the national programs of the region on sorghum improvement.

Since the establishment of the network, the regional sorghum researchers have had frequent opportunities for interactions, germplasm and information exchange. Four annual regional workshops were conducted, regional trials were organized and conducted, a regional introduction nursery was organized and evaluated, and a regional cooperative sorghum screening nursery was organized and completed. Because of these activities sorghum improvement in the region operates as an effective network.

The main objectives of the regional trials were to evaluate the elite varieties available in each national program across the entire region and to find out the range of acceptance, in the region, of a given variety. The participating national programs have identified outstanding varieties from these trials and are using them for further testing, production and/or as parents in their breeding programs. The regional trials were organized for and conducted in the four major sorghum adaptational zones of the region.

Although the data from the very dry lowlands would have been most interesting and appropriate for this symposium, most of the trials grown under such conditions have failed because of shortage of moisture and the data obtained is erratic and unreliable.

Grain yield results from the low elevation trials grown at eight locations in the 1983/84 seasons in seven countries are given in Table 3. There was no variety which appeared superior across all locations. However, under each location, a number of introduced varieties performed better than the local check. At Katumani, Kenya, the highest yielding entries were Badege, 5DX 160, and Urumimbi. At Serere, Uganda, the best yielders per ha were the only two local developed entries Serena (2860 kg) and 5DX 160 (2590 kg) while at Ilonga, Tanzania, the highest yielding variety was Gambella 1107 (5444 kg) followed by Serena (3889 kg). Two varieties, 5DX 160 and E525 HT, produced over 5 tons/ha at Karama, Rwanda. Out of these promising varieties, commercial quantities of seeds of Serena and Gambella 1107 only are available in the region.

Regional Nursery

In order to promote the systematic movement of sorghum germplasm and breeding lines among the national programs of eastern Africa, the Morogor (Tanzania) workshop of 1984 of the Eastern Africa Sorghum and Millet Improvement Network recommended that an Eastern Africa Cooperative Sorghum Screening Nursery (EACSSN) composed of the most promising and advanced breeding lines from Ethiopia, Tanzania, Uganda, ICRISAT/Hyderabad, and SAFGRAD/ICRISAT/Kenya be organized for multi-locational testing in Ethiopia, Kenya, Tanzania, and Uganda in 1985. It was also recommended that after the initial evaluation, the selected best entries from the EACSSN be made available to the non-participating national programs of the region for testing and use. Accordingly the EACSSN was organized for the 1985 crop season with the following contributions (Table 4):

Table 3 Grain yield (kh ha^{-1}) of the Low Elevation Set of the EACSRT, 1983/884

Identification	Seed source	Katumani Kenya	Serere Uganda	Taiz YAR	Zabid YAR	El-Kod PDRY	Ilonga Tanzania	Panmure Zimbabwe	Karama Rwanda
Tajarib	YAR	1120	1180	2180	640	2370	278	2200	1886
SEPON 80-1	YAR	910	950	3420	1390	3800	3056	3800	1932
5DX 160	Burundi	2210	2590	1340	1490	2770	2944	3800	5773
Serena	Uganda	1560	2860	2580	1510	3130	3889	4100	3980
Seredo	Uganda	1630	2610	3300	1490	2900	1944	4700	4998
E525HT	Uganda	1970	1900	2640	1490	3000	3833	3900	5063
2KX 17/13/1	Uganda	310	600	3080	1060	2070	3056	4500	1745
Tegemeo	Tanzania	530	460	1810	1240	1430	2111	3800	2812
2KX 17/6	Tanzania	1190	480	1680	1180	1270	2944	2500	3659
Gambella 1107	Ethiopia	1310	1070	2770	1080	2770	5444	4200	1799
Melkamash 79	Ethiopia	1140	1030	2300	1220	2870	2722	3600	1075
Badege	Rwanda	2590	1900	-1	120	2070	1500	-1	3111
Urumimbi	Rwanda	2120	2630	-1	120	1330	1278	-1	3507
76T1-23	Kenya	380	2100	1430	1410	1330	1056	4300	1824
IS 8595	Kenya	-1	1160	840	290	1370	555	-1	1259
Local check	Local		1840	2920	350	1730	3833	3500	3317
SE		±413	±590	±237	±104	±231			
Mean		1430	1590	2260	1010	2240	2523	3800	2984
CV(%)		49.6	59.9	18.2	17.9	17.9	40		
Local Check		76T1-23	E1937	Unknown	Gairaia	Beini	Serena	Chisumbanje	Tura

-1. = Not included in calculation of SE.

Table 4 Contributions of Participants to the EACSSN project

Contributor	No. of entries contributed	1985 EACSSN No. range
Ethiopia	180	1 – 180
Tanzania	200	181 – 380
Uganda	200	381 – 580
ICRISAT/Hyderabad	196	581 – 776
SAFGRAD/ICRISAT/Kenya	224	777 – 1000
	Total = 1,000	

The main objective of the EACSSN was to identify the most promising sorghum lines for wide use in the national programs of eastern Africa. The 1985 EACSSN took entries suitable for and concentrated on only the low elevation sorghum ecological zone of eastern Africa (<1500 m altitude). The nursery was planted only at Alupe (Kenya), Serere (Uganda), and Nazreth (Ethiopia). Single row plots of 5 m length with two replications were used at each location for each entry.

A suitable local check was planted at regular intervals at each location. As planned, nursery monitoring tours were organized and all contributors to the EACSSN travelled to each location as a team to evaluate and select the best entries at each location.

Based on the overall agronomic desirability score at one or more of the three planting sites, 150 best entries were selected for further multi-locational testing. The total number of entries selected for advancing at Alupe, Nazreth, and Serere were 32, 68, and 83, respectively. Only two entries 1985 EACSSN No. 92 and 550, (SC-108-3X C5-3541)-19-1 and 12X46/F_4/2M/5, respectively, were selected at all three sites. However, 28 entries were selected at two sites. All others were selected at one location only. At Serere, as expected, the most promising entries were those tracing to that program although a few lines from Ethiopia were promising there. At Alupe, most selections traced to Ethiopia, Uganda, and the SAFGRAD/ICRISAT/Kenya materials. At Nazreth, the selections were spread out covering all sources with the majority tracing to the Ethiopian program. It is necessary to repeat the evaluation of the EACSSN over several seasons to establish the pattern of varietal adaptation in the low elevations of eastern Africa so that intelligent movement of germplasm and breeding materials could be effected in the region.

Sorghum Research Stations in Eastern Africa

One common feature of future plans of all the national programs of eastern Africa is that they give high priority to the development of high yielding cultivars suitable for the various major ecological zones of the country. The plans further specify that such cultivars must be accepted by the local consumer and should be resistant to the various pests and diseases dominant in each country.

To cover all the major ecological zones of the region, to strengthen the functional networks of stations among which germplasm and research results are transferable and to continue to facilitate multi-locational evaluation of introductions, germplasm, and breeding stocks, it is essential to continue to use stations of national programs for each ecological zone. Some countries are interested in selected ecological zones only and therefore they should be encouraged to participate in activities relevant to zones of their interest. The major sorghum research stations in the region covering the major ecological zones are:

Rwanda	: Rwerere, Rubona, Karama
Burundi	: Kisozi, Moso, Imbo
Tanzania	: Hombolo, Ilonga, Ukiriguru
Kenya	: Katumani, Kakamega, Lanet, Alupe
Uganda	: Serere
Ethiopia	: Nazreth, Alemaya, Kobo, Bako
Somalia	: Afgoi, Bonka
Sudan	: Wad Medani, Abu Naama, Samsam

Seed Production

One of the constraints to the rapid movement of improved varieties in the region is the lack of effective seed industries. Kenya is the only country which has a good and well established seed industry; even the Kenya Seed Company does not pay very much attention to sorghum. In the last two years, mainly because of the severe drought in the region, there was very high demand for early maturing lowland sorghum seed in the region but nobody was in a position to satisfy all the demands. Such demands for improved seeds will certainly continue, and it is, therefore, essential to strengthen the seed industry of each national program.

Looking Ahead

A further effort in the expansion and strengthening of sorghum research in eastern Africa using the networking model is needed. The major thrust of such an effort should be to strengthen each of the national programs of the region in all ways including equipment, supplies, training and operations. A strong national program is mandatory to bring about significant improvements in sorghum production in each country of the region. A networking activity is also essential to foster close ties among the national programs of the region.

An eastern Africa sorghum and millet improvement network should be established to continue coordinating regional services in cooperative regional trials and screening nurseries; introduction, evaluation, distribution, and utilization of germplasm; organizing annual workshops and cooperative nursery monitoring tours.

To make the regional network more effective disciplines needing further support or expansion, in order of priority, are breeding, agronomy, *Striga* research, entomology, pathology, and grain utilization research. An effective network coordinating center will need sufficient support in finance and support staff as well as addition of professional staff in selected areas.

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12 A Regional Effort for the Improvement of Sorghum in Southern Africa

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Introduction

At their Lusaka meeting in March of 1980, the Heads of SADCC States, requested ICRIST to establish a research centre in Botswana. Their focus was to increase research on crops for semi-arid areas. ICRISAT sent a mission into the region in November of 1980 and they recommended the establishment of teams situated at appropriate places for the crops involved. Bulawayo (and Matopos) was identified for the sorghum-millet programme. This recommendation was accepted by the Council of Ministers in 1982, and paved the way for development of the regional sorghum-millet improvement programme.

Objective

The primary objective of the Regional programme is to strengthen national research capability for the improvement of sorghum and millets. There are 3 major response areas focused on this objective: research for crop improvement, manpower development via education and training programmes, and service, i.e. such activities as providing off-season opportunities for SADCC country programmes to increase their rate of crop improvement and conditions of field research. There is also a plan to contribute to experiment station development and management by upgrading facilities and by training.

Regionalization

There is growing interest in some form of regional research capability. It is a worthwhile experiment and if successful can be cost effective. The insect, disease, and weed pests are common across the region. Evaluation seeking resistant varietal material need not be done by each country but can be done by a regional programme in the best location for each relevant trait. In the case of the SADCC/ICRISAT programme, ICRISAT is rapidly bringing together a multi-disciplinary team to generate a regional structure of research and training that can, over time, become a fully supported SADCC activity under SACCAR.

Introduction and Genetic Diversification

The regional programme has begun with the introduction of breeding stock of Sorghum, Pearl and Finger Millets from breeders around the world, as well as germplasm collections primarily from Southern Africa. These introduction nurseries have been evaluated in 4 to 7 locations in the SADCC region. From these nurseries we are able to diversify genetic variability for selection. This has laid a useful base for initiation of the Regional Programme. Constant introduction and evaluation in different environments of the region will be a continuing process and can be a service in reducing poorly performing material before going to National Programmes. Introduced material will be safely stored for future use; and over time, classified for valuable traits.

Crop Improvement for Dry Areas

The first priority is yield and stability of yield involving both varieties and hybrids across the array of environments in SADCC. Drought resistance, resistance to leaf disease and stemborers are high priorities as well as grain quality and crop utilization.

The array of additional traits for which priorities are being established are: resistance to downy mildew, virus, *Striga*, aphids, shootfly, midge, head bugs, and acid soils with aluminium and manganese toxicities. "Hot spot locations" in the region are being located for screening and evaluation of these traits. It is necessary to identify priorities for each of the important agro-climatic zones of the region. To help establish priorities and identify "hot spot" locations advice from consultants, discussions with our colleagues, and our studies in the region have provided useful results. Clearly, it will take several seasons to finally establish priorities for research because of seasonal variation in expression of traits. Ranking or weighting of priorities is considered an important and necessary exercise. It is recognized that there is a need to undertake development research for some traits and to adapt techniques and materials developed in other locations for some other traits in a form of international networking.

Previous speakers have very adequately covered important aspects of improving crop yields in moisture stress situations, and only a few comments will therefore be added.

i. Several speakers have mentioned the value of looking at aspects that correlate with drought resistance, i.e. leaf temperature, stem elongation, waxy cuticle, osmotic adjustment etc. The picture can be broadened to include resistance to leaf blight and stemborers. Techniques need to be carefully developed to evaluate each trait individually. The experiment must be controlled so that the main effect is well expressed. To gain the necessary control, measures may be required that a farmer would not take – the scientist and his director need to appreciate this point.

ii. A complete phenotypic alteration may be valuable. For example, Guinée sorghums are common in many parts of semi-arid Africa. They are well adapted but very difficult to improve or modify by breeding. This is a case where major phenotypic alteration, possibly using exotic varieties, but possibly carrying some *Guinée* traits, may be a useful approach. Otherwise, alterations in height, maturity and photoperiod sensitivity are common.

iii. The yield of hybrids as compared to varieties has been found to be proportionately better in stress compared to non-stress situations. All breeders should develop and evaluate hybrids even if there is no seed industry. A high yielding hybrid, such as Hageen Dura No. 1 in the Sudan, may lay the base whereby a seed industry can evolve. It is relevant that locally developed hybrids invariably yield better than introduced ones.

iv. Comments have been made at this symposium about the spread of maize even into marginal growing situations. The yield potential of sorghum is about the same as that of maize. Considerable research on maize in the SADCC Region has resulted in the farmer availability of high yielding hybrids – it will be relevant to develop sorghum hybrids to compete: Once done, a base is provided for farmers to hedge against the vagaries of weather by splitting their hectarage between maize and sorghum. To a degree this is already done in traditional drier tracts of the region. To further facilitate this comparison, incorporation of the best available sorghum variety or hybrid in maize trials and the best maize variety or hybrid in sorghum trials over locations and seasons should be encouraged. From such testing, recommendations will be possible.

v. Much has been said about farming systems. A farming system involves crops which can be viewed as building blocks. The best system will be built from taylor made blocks. Crop improvement is a relevant partner in a farming system endeavour.

vi. One area of deep concern is shifts in pest problems with change in crop variety. Already, in Zambia, ZSVI, a new variety introduced from ICRISAT, is attracting high populations of stemborers in fields cropped for several years to the variety; and the variety is showing high susceptibility to a virus. Such problems would be identified as soon as possible and steps taken to counter them.

Crop Management

Management practices are important. Clearing of crop residue can greatly reduce stemborer problems, breaking a hard pan can permit better water penetration, reasonable soil fertility can boost crop growth greatly enhancing yield. Rapid seedling growth helps plants escape damage by shootfly, good nitrogen availability can reduce *Striga* attack, herbicides will help control weeds but undesirable interactions with the crop need experimental verification. Proper equipment to place seed into moisture and at uniform depth is a factor in realizing good stands. Uniform row to row spacing facilitates better cultivation hence weed control. Sowing date is important in avoiding attack by shootfly and is a factor in avoiding sugary disease. While we have not yet been able to address such management related problems in the SADCC/ICRISAT regional programme, we anticipate doing so particularly with the joining of an agronomist later in the year. These problems will be examined in SADCC/ICRISAT Regional programme in the future.

Food Quality and Alternate Crop Uses

There are also plans to include research on sorghum-millet grain quality. Seed hardness contributes to good storage and milling. Simple tests to evaluate large numbers of samples particularly for making stiff porridge and as a source of malt for brewing will be established. These are important factors to the traditional farmer.

Additionally, there are plans for the development of technology around the use of sorghum to enhance its market opportunity. Beside being used as a malt source by large brewers of traditional beer, Zimbabwe is interested in using sorghum to extend wheat flour and Zambia is planning to construct a plant to make molasses. The dairy industry in Zimbabwe is interested in animal feed and in Botswana there is interest in developing a forage with good resistance to moisture stress. Although it would require study, there may be a place for production of alcohol and biogas.

The programme is at an exploratory stage when attempts are being made to look at an array of opportunities to better utilise the crop traditionally and as a cash crop in the market.

Conclusions

1. While recognizing the importance of resistance to moisture stress, it is important to rank priority traits for the various agro-ecological situations in the SADCC Region to determine research strategies.
2. A regional crop improvement programme can be a cost effective way to undertake many research problems in the region and can contribute to strengthening national research capability. The regional programme develops a network and also participates in a world-wide network of research and development.
3. Education and training programmes are being established to reduce the problem of lack of qualified manpower to undertake crop improvement activities on sorghum and millets..
4. Concern is expressed about conditions for doing quality field research and plans to contribute to improving experiment station development and management, through an educational–training component.
5. In the region, a service will be provided to speed the rate of breeding progress via an off-season nursery – crossing block opportunity, and to continually introduce and evaluate across a range of priority traits.

13 Improvement in Stand Establishment in Pearl Millet

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Abstract Inadequate crop stands are a common feature of pearl millet fields in arid and semi-arid areas in both Sahelian Africa and in India. Studies in Niger and Rajasthan State (India) indicate that low soil moisture and associated high soil temperature are among the major causes of stand failures; seed quantity and quality are usually not limiting factors.

Field and laboratory screening methods have been developed to evaluate genetic differences in tolerance of high soil surface temperatures and low seedbed moisture levels for both initial emergence of seedlings and for post-emergence survival. Initial results indicate that there is genotypic variation in pearl millet for tolerance to most of these problems. Reasons for differential tolerance are not known at present, but it should be possible in the near future to commence routine screening of selected breeding materials for better stand establishment capability.

The possibility of eventually breeding for better stand establishment capability will depend on (1) field evaluation of the benefits of the differences that exist and (2) the outcome of future studies on the heritability of these differences.

Crop establishment is often cited as a production problem for pearl millet (*Pennisetum americanum [L.] Leeke*) in both arid and semi-arid areas. Farmers are frequently obliged to sow several times to attain an acceptable stand of plants, even with the relatively low plant populations common to these areas, particularly the Sahelian zone of West and Central Africa (Catherinet *et al.*, 1963; ICRISAT, 1983). Resowing increases the labour requirement for the crop, and crops from late sowings often yield less than those from sowings with the first rains (Charreau, 1974). Improved establishment would be a definite benefit if it could be attained, by either improved tillage and sowing methods or by millet cultivars with better tolerance to those factors which cause poor establishment.

Causes of Poor Crop Establishment

Poor crop stands can occur for a variety of reasons: poor seed quality, poor seedbed preparation and sowing methods, failure of emergence, and failure of emerged seedlings to survive (see also table 1). As each of these factors requires a different solution, it is essential to understand the major cause(s) of stand failure in a given location before improvement can be sought. Several studies carried out by the authors to better understand the specific reasons for stand failure (ICRISAT, 1982; ICRISAT, 1986) illustrate the differences which exist.

In studies in several villages in India and in Niamey Department, Niger, the quality of seed of pearl millet sown by farmers has generally been good (Soman *et al.*, 1984b; Soman, unpublished).

With a few exceptions, insect damage is low (<10%) and germination in standard laboratory tests is good (>80%). Seed quality therefore may be only an infrequent cause of poor stands. Similarly sowing rates were generally adequate (Fig. 1)

Actual field emergence percentages in these same studies however were low, often in the range of 25% or less of seeds sown. In Dhandhan village, Sikar District, Rajasthan in 1983, for example, actual plant stands at 5 days after sowing (DAS) represented less than 10% of the seeds sown (Fig. 1), which resulted in plant populations well below recommended ones in all cases, and stand failures in many cases. Even under optimal conditions on research stations emergence rates for pearl millet are seldom more than 50% of the seeds sown (Lawan *et al.*, 1985, Soman, unpublished), although laboratory germination rates of 90% are regularly reported. Emergence rates of 50% can be easily compensated for by adjusting sowing rates, but emergence rates of 10% can seldom be, as emerged seedlings in these conditions are frequently too unevenly distributed to provide even stands.

Analyses of seedbed environmental data from the Dhandhan study suggested that low soil moisture and high soil temperature in the seed zone during germination/early emergence (1 – 2 DAS) were at least partly responsible for the poor emergence observed. Mean seed zone moisture ranged from 1 to 6% (in soils with >90% sand) at 1 DAS, accompanied by midday soil temperatures of 36 to 44°C.

Post-emergence death of seedlings is also a common problem, particularly in the Sahel, and can reduce acceptable plant stands at emergence to stand failures within one to two weeks time (ICRISAT, 1986). In the study in Niamey Department, emergence calculated on a hill basis (at least one emerged seedling per hill) averaged 80%; but hill populations declined from

Table 1 Factors affecting crop establishment of pearl millet in farmers' fields.

Factors Affecting Seedling Emergence:
Seed Factors
– Seed viability and dormancy
– Seed size and density
– Plumule length/growth rate
Management Factors
– Timeliness of sowing
– Sowing depth
– Seed-soil contact
Environmental Factors
– Soil moisture
– Soil temperature
– Soil crusting and compaction
Factors Affecting Post-Emergence Survival:
Seedling Factors
– Vigor and growth rate
– Root establishment
Environmental Factors
– Soil moisture
– Soil temperature
– Soil fertility

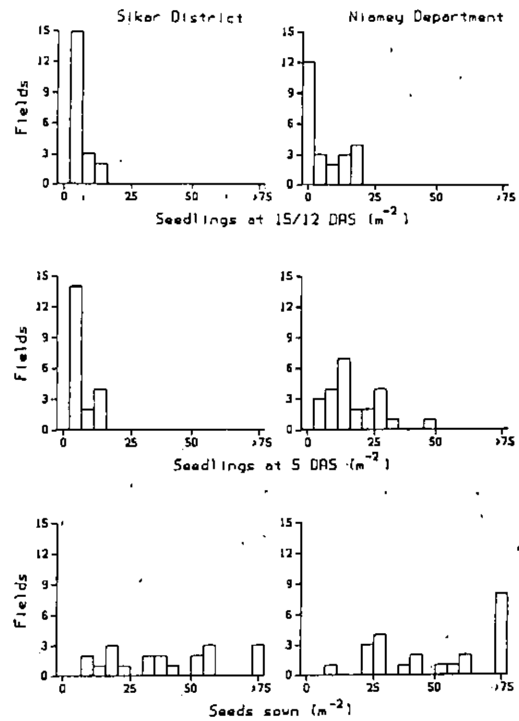

Figure 1 Distribution of seeds sown (bottom), emerged seedlings (center), and surviving seedlings (top) in farmers' fields in Sikar District, Rajasthan, India in 1983, and Niamey Department, Niger in 1985.

a mean of 4900 hills ha^{-1} at 5 DAS to 2300 hills ha^{1} at 12 DAS, with stands failing completely in nearly half of the fields (Fig. 1). An analysis of environmental conditions measured during the period indicated that high soil surface temperatures (>50°C at midday) were primarily responsible for the stand loss. Such temperatures are common in this area if the initial sowing rain(s) are followed by a period of dry, clear weather and surface soil moisture evaporates (ICRISAT, 1983).

Improvement in Stand Establishment

The origin of a stand establishment problem obviously determines the appropriate solution. Seed quality can be improved by selecting better seed material from the previous crop (Okonkwo and Vanderlip, 1985), and by improved storage conditions. Poor emergence due to incorrect sowing depth, poor seed soil contact, etc., can be improved by better sowing equipment and/or methods. Stand loss due to covering of seedlings by wind or water transported soil materials can be reduced by land surface treatments, wind breaks, etc. to reduce such covering (ICRISAT, 1985).

Stand failures or losses due to unfavourable seedbed moisture and temperature conditions are less feasible to control by cultural methods, and improvement must be sought through genetic tolerance of the factor responsible for the stand failure. Breeding for such tolerance is a relatively new area, but the procedure for doing so is similar to that for breeding for resistance to pests or diseases (Bidinger *et al.*, 1986). This necessitates an understanding of the problem, the development of screening methods and the assessment of genetic variability for tolerance, and an evaluation of the response to selection for improved establishment ability.

This paper will review the results of the authors' research, which has been designed to lay the foundation for future efforts in breeding for improved crop establishment ability. Emphasis is on the development of screening methods for specific problems, and on the assessment of genetic variation for tolerance to the causes of the problems.

Seedling Emergence from Low Moisture, High Temperature Seedbeds

Screening Techniques

A field screening technique has been developed to simulate the low moisture, high temperature conditions which can occur in a seedbed following sowing done on an isolated, light, rainfall (15 – 20 mm) which is then followed by clear dry weather (Soman, unpublished). The screening is done in the hot dry season before the beginning of the monsoon (March – May) when atmospheric conditions result in rapid drying and heating of the seedbed soil.

Seeds are sown into dry soil on raised beds 1.2 m wide with 4 rows to a bed. The soil surface is smoothed and a gradient irrigation applied using the line source technique (Hanks *et al.*, 1976). This produces a linear gradient of applied water from about 30 mm closest to the sprinkler line to 5 mm at the farthest point, covering seven beds. The beds are sown such that each test entry appears in each position (bed) along the gradient in the useful range of 10 to 25 mm of applied water. Seedbed temperature (2 cm) is monitored hourly by an automatic data logger and seedbed moisture (0 – 5 cm) is measured daily by gravimetric means (Fig. 2). Test entries are replicated either once or twice on both sides of the line source. Comparisons are made of genotype emergence in several beds, including both adequate (wet) and inadequate (dry) moisture for full emergence. Data are expressed as emergence in the dry seedbed conditions relative to that in the wet conditions.

A second, laboratory-based method to assess germination response to high temperature has also been developed (Soman and Peacock, 1985). In this method seeds are sown in closed but unglazed clay pots which are placed in a water bath with the water level controlled to maintain an optimum (not saturated) soil moisture in the seed zone of the pot. A bank of infra-red lamps are placed above the water bath; these are used to heat the soil surface in the pots in a simulated natural diurnal temperature cycle (Fig. 3). The maximum temperature of the cycle is adjustable from <40 to 50°C, thus allowing any degree of temperature stress to be put on germinating/emerging seeds without the common confounding effects of inadequate seedbed moisture. Data are expressed as a percent emergence (of the seeds sown).

Evidence for Genetic Variation

Differences between both landrace and improved varieties have been found in ability to emerge in low moisture, high temperature seedbeds. In fact in

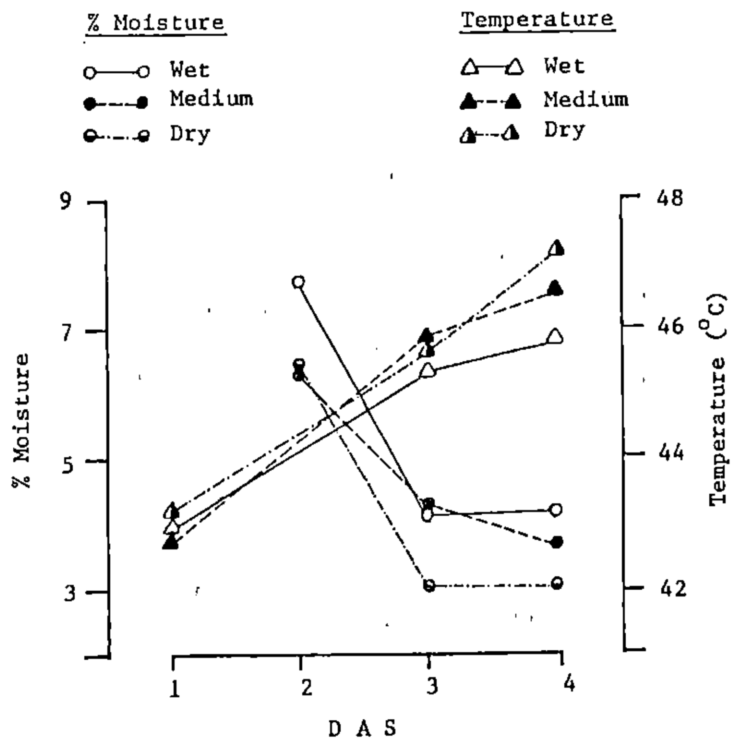

Figure 2 Changes in surface soil moisture (0 – 2.5 cm) and temperature (2 cm depth) with days after sowing (DAS) in a field screening for emergence under high temperature, low moisture seedbed conditions.

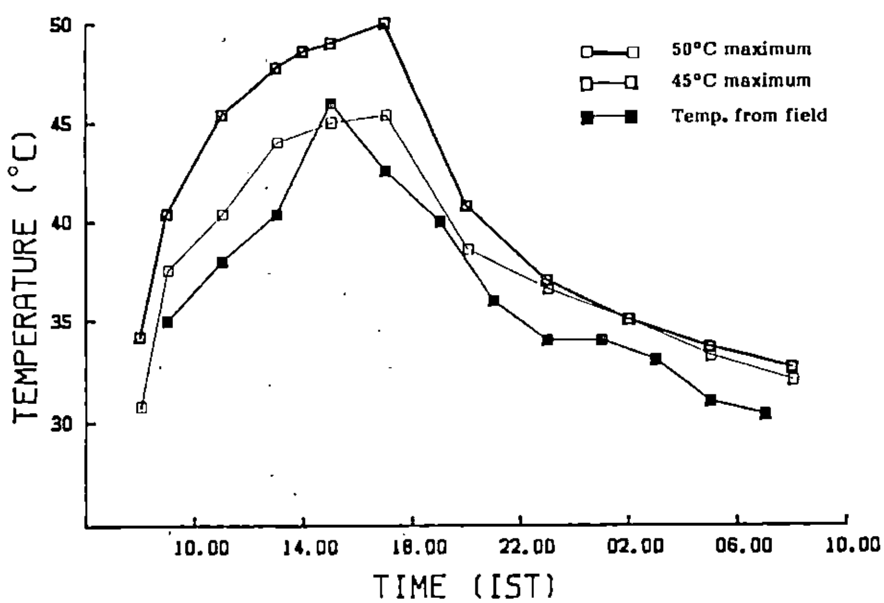

Figure 3 Diurnal variation in soil surface (2 cm depth) temperature under infrared lamps, in comparison to diurnal variation in soil surface temperature (2 cm depth) under field screening conditions.

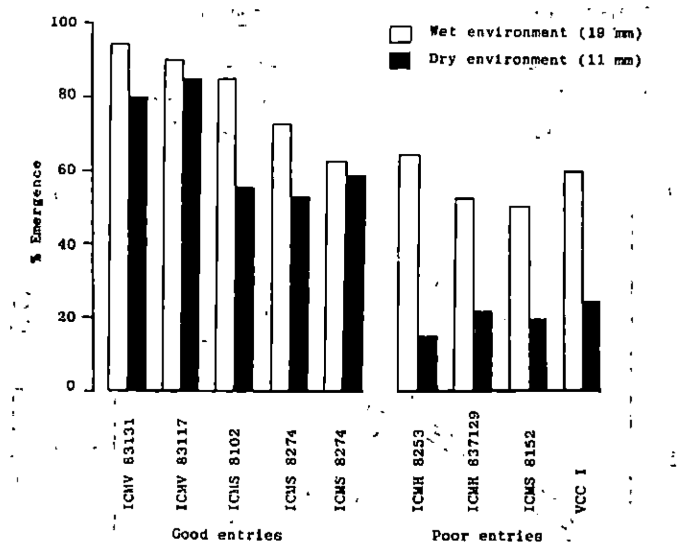

Figure 4 Percentage emergence of selected entries from the International Pearl Millet Adaptation Trial, 1985, under high temperature, low moisture seedbed conditions in the field.

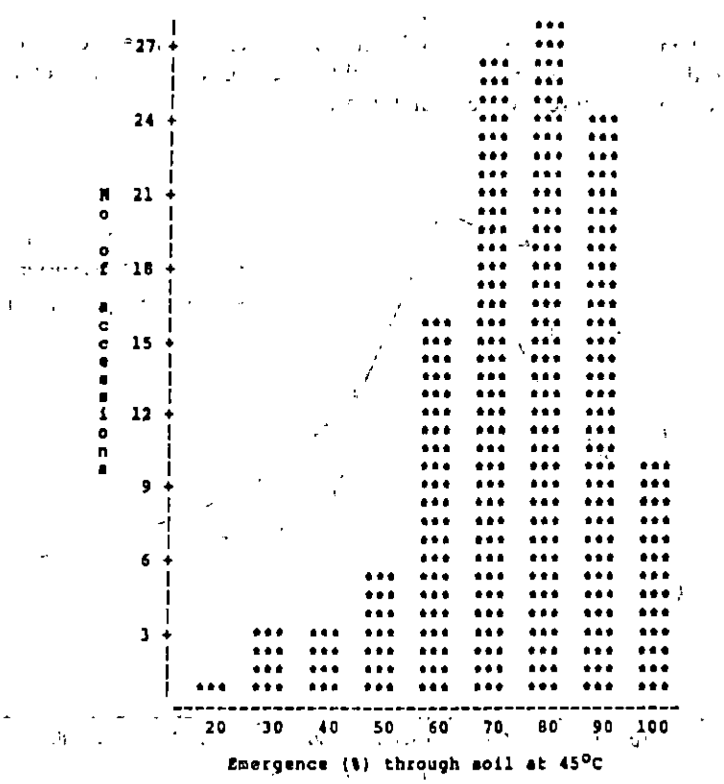

Figure 5 Percentage emergence of germplasm accessions at a soil surface temperature of 45°C, under infrared lamps.

certain cases the differences have been surprisingly large. In a recent evaluation of entries in the International Pearl Millet Adaptation Trial, 1985, the range of emergence in the drier end of the moisture gradient (11 mm of water applied) was from 11 to 85%. Six entries had greater than 50% emergence in these conditions and two emerged as well in the dry as in the wet (19 mm water applied) environment (Fig. 4).

These results were considered encouraging as no previous effort had been made to select these entries for emergence ability. If this amount of variation is a general pattern, early screening of varieties under consideration for wider testing may be sufficient to eliminate those with poorer emergence capability from further consideration. This would simplify the procedure for improving stand establishment capability considerably.

More experience is available in screening pearl millet for the ability to emerge in high temperature conditions alone, as the technique using the infra red lights has been available longer. A comparison of 117 genetic resources accessions from the state of Rajasthan (India), six Sahelian and two Southern African countries indicated considerable genetic variation for emergence ability at a moderately high (45°C) daily maximum soil surface temperature (Fig. 5). Increasing this temperature to 50°C reduced the mean per cent emergence from 71% at 45 to 36% at 50°C, and the range from 20 – 100% to 0 – 30%. Eight per cent of the entries however still achieved a satisfactory (>60%) emergence at 50°C. This suggests that if there were a need to breed for emergence capability from such extreme temperatures, sources of tolerance are available.

Seedling Emergence from a Crusted Soil Surface

Screening Techniques

This technique (Soman *et al.*, 1984a) is done in the field in the dry season as in the previously described seedling emergence technique. Seeds are sown on adjacent pairs of 1.2 m wide beds in a dry soil, which has been worked to a very fine tilth to favour surface crust formation. The tops of the beds are smoothed with a bed shaper following sowing and a uniform sprinkler irrigation of approximately 30 mm is given using two sets of overlapping line source systems placed at the edges of the test area. The action of the sprinkler-applied water drops on the smooth soil surface provides the conditions necessary for crust formation during the following 2 – 3 days, if evaporation rates and temperatures are high. One day before the expected time of seedling emergence the surface crust on one of the pair of beds is broken using a rolling crust breaker; this provides a control treatment to measure the potential maximum emergence under the experimental conditions, but in the absence of the crust. Soil temperature and moisture are monitored and crust strength assessed daily (Fig. 6). Genotype emergence is expressed as the ratio of seedlings emerged in the crusted treatment to those emerged in the control (c/u ratio).

Evidence for Genetic Variation

Pearl millet in general does not emerge well in crusted soil conditions compared (for example) to sorghum as the millet seedling is smaller and less capable of actually breaking a surface crust. There are, however, some differences among lines, and a recent test of germplasm accessions from

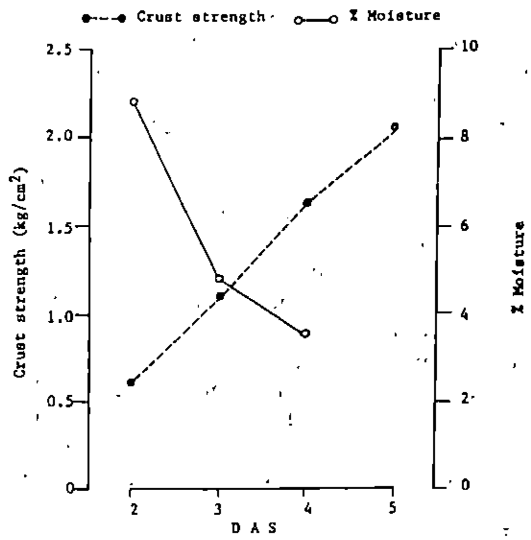

Figure 6 Changes in crust strength and soil surface moisture (0 – 2.5 cm) with days after sowing (DAS) in a field screening trial for seedling emergence in crusted soil conditions.

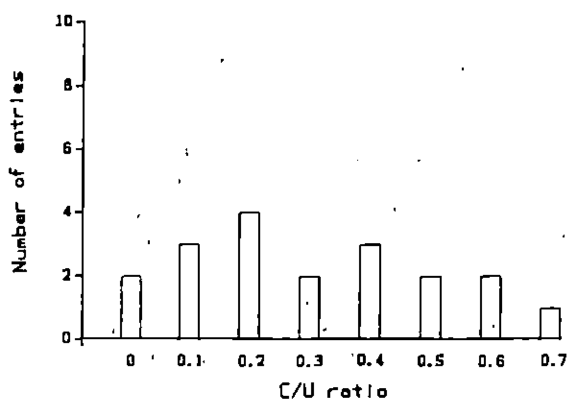

Figure 7 Emergence of entries in the International Pearl Millet Adaptation Trial, 1985, under crusted soil conditions. Data are the ratio of emergence in the crusted to the noncrusted conditions (C/U ratio).

Southern Africa has identified some lines with a reasonable emergence ability.

The same International Pearl Millet Adaptation Trial reported in the previous section was also screened for emergence in crusted soil conditions (Fig. 7), the results typify those generally observed with pearl millet. The majority of the entries failed to achieve a satisfactory emergence, only five reached 50% and one, 70% emergence. Breeding to improve emergence ability in crusted conditions would probably require a greater effort, perhaps including crosses with the existing lines showing the best capability and

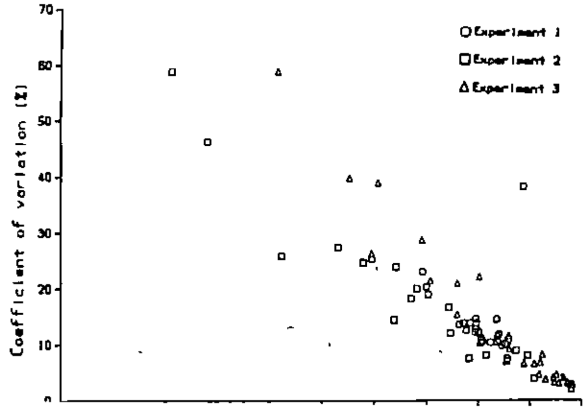

Figure 8 Relationship of percent seedling survival and experimental coefficient of variation for three field experiments on seedling survival in high temperature, low moisture conditions.

intensive screening of progeny. Nothing is known however of the inheritance of the ability of emergence from a crusted soil or the mechanisms by which some few lines are successful.

Seedling Survival in High Temperature, Low Soil Moisture Conditions

Screening Techniques

Screening for seedling survival in combined high soil temperature, low soil moisture conditions is done under field conditions in the latter part of the dry season, prior to the rains. Seeds are planted and given 25 mm of irrigation by sprinkler, which is adequate for 100% emergence. Control plots (wet plots) continue to be irrigated as required. Stress plots (dry plots) receive no further irrigation. Under such conditions, there is a strong inverse relationship between coefficient of variation (CV) and the mean percentage survival in the dry plots (Fig. 8). The time of release of the stress (when an irrigation of 25 mm is given to the dry plots to accurately determine the number of surviving plants) has been experimentally determined in terms of the estimated percentage survival in a standard resistant check at which the expected CV will allow the desired degree of discrimination among entries. (This is about 70% with local Heini-Kheiri landrace as the resistant check). Soil surface temperatures are monitored regularly in both treatments and data are expressed as per cent survival and seedling growth in the dry as compared to the wet plots.

An attempt is also being made to modify the laboratory technique used to evaluate emergence under high soil surface temperature, in order to evaluate the ability to survive high soil temperatures following emergence, without the associated effects of a rapid loss of soil moisture. Plastic pots containing 10 seedlings each are set in a water bath placed under a bank of infra-red lamps. Seedlings are subjected to various periods of high (45 – 50°C) soil surface temperatures, both continuous and with alternating non-stress periods, as would occur in field conditions. Additional work is

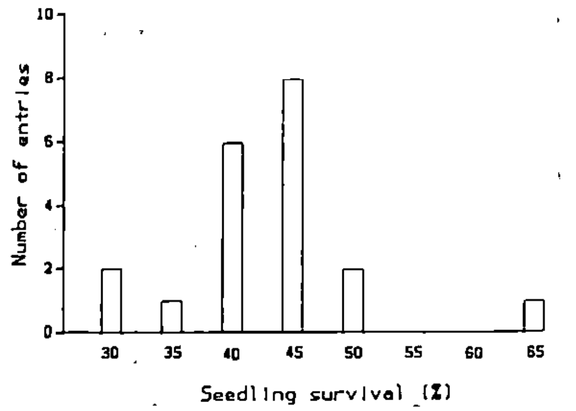

Figure 9 Seedling survival of entries of the Pearl Millet Multilocation Drought Trial, 1985, under high temperature, low moisture conditions.

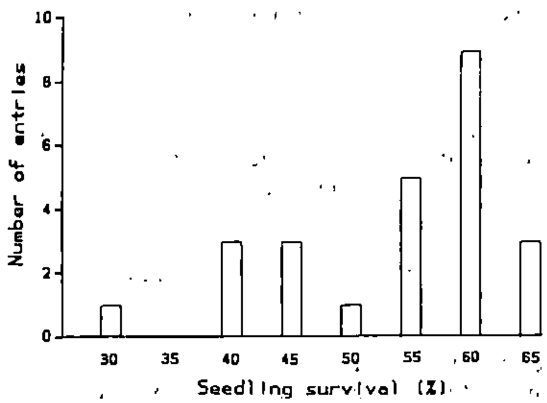

Figure 10 Seedling survival of a collection of landrace varieties from West Africa under high temperature, low moisture conditions.

required on this methodology, but initial results (see below) have been promising.

Evidence for Genetic Variation

A number of comparisons of materials of Sahelian-origin with non-Sahelian materials have demonstrated the clear superiority of the former in surviving long periods of stress at the seedling stage. For example, a group of Indian lines under evaluation for drought tolerance (at the adult plant stage) were all markedly inferior to the local Heini-Kheiri landrace at Sadore, Niger in ability to survive a period of seedling stress (Fig. 9). The landrace had 65% stand survival compared to 51% for the next best entry and a 42% average of all lines. Similar differences exist between African varieties of Sahelian and non-Sahelian origin; nearly all of the entries with less than 50% survival in the comparison of mostly Sahelian landraces shown in Fig. 10 are of African but non-Sahelian origin. Whether or not there are important differences among Sahelian landraces is not known.

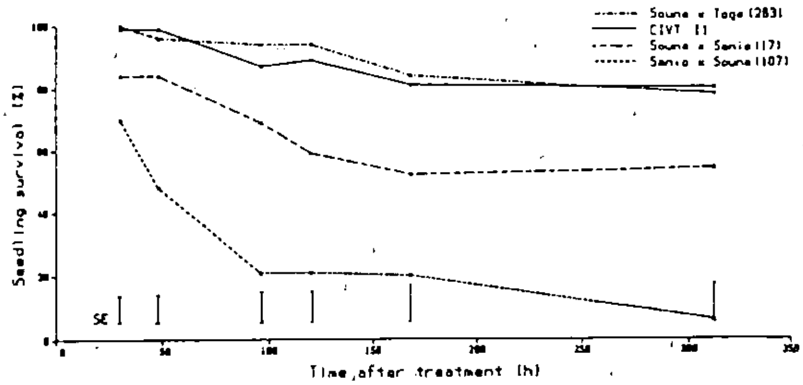

Figure 11 Seedling survival of selected pearl millet lines following the initiation of a 48 hour period of high temperature (48°C) treatment under infrared lamps.

Limited experience in screening new breeding program products indicates that there may be large differences in such materials, and that those including parents from non-Sahelian areas may have poor seedling survival capabilities under Sahelian conditions (ICRISAT, 1986). Results were generally encouraging however, in that some new varieties did have a tolerance equal to that of the local Sadore' landrace, which was used as the tolerant check. New varieties for the Sahelian zone clearly need to be screened for establishment capability as early as possible in the breeding process to discard those which are not able to tolerate seedling stress conditions.

Results from the laboratory infra red screening system for high temperature tolerance are limited, but have indicated that clear differences exist among the limited number of genotypes tested, (Fig. 11). As in the case of the field screening, certain lines were found with a tolerance equal to that of the check variety (CIVT in Fig. 11). Further experience with this technique is necessary however to confirm that the direct measurement of heat tolerance does predict the field tolerance of the combined temperature and moisture stress.

Breeding for Improved Crop Establishment Capability

It is clear from results reported in the previous sections that there are often significant differences among released or advanced varieties in crop establishment ability. Where crop establishment is a problem, it would seem that routine screening of advanced varieties for establishment ability should be initiated, mainly to discard those entries which do not establish as well as the varieties commonly grown by farmers. The number of varieties in the advanced stages of testing is often small, so the resources required for such screening are not large. As the objective of such final evaluation is generally to reduce the number of varieties to one or two for on-farm testing, any evaluation procedure (e.g., consumer acceptance, pest resistance, establishment ability, etc.) which assists in this is useful. This is particularly true if the yield differences among entries are small/non-existant, and cannot therefore be used to eliminate entries.

Some additional field evaluation of the differences among varieties identified in the screening procedures would probably be advisable before routinely using these procedures, however. The performance of the tolerant and susceptible checks in several of the procedures has been confirmed in field plantings, as part of the procedure of selecting these as checks. These represent extreme differences, however, and it could be useful to determine how well intermediate entries in the screening tests perform under natural field conditions. Such information would assist in evaluating the significance of small (but statistical) differences recorded among entries in the screening procedures.

The longer term use of these screening procedures for direct selection for seedling establishment ability in the early stages of a breeding program will depend on the results of future studies on the heritability of differences in establishment among genotypes. Early generation selection requires screening a much greater number of lines, over more than one generation, and requires that screening must fit into a fixed calendar determined by other selection procedures. Seedling establishment must be sufficiently heritable to justify this increased expenditure of time and resources. Nothing is known of the heritability of seedling establishment at present; work is just beginning to assess this. The results will determine how (and if) selection for establishment ability can be best integrated into the early stages of a breeding program.

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14 Strategies for the improvement of sorghum and millet in semi-arid Kenya

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Abstract About 72% of the land mass of Kenya is arid, receiving less than 500 mm annual rainfall, 13% is semi-arid, receiving from 500 to 750 mm, 12% has high agricultural potential, receiving 750 to 1250 mm and 3% receiving more than 1250 mm.

This paper briefly outlines the strategies for improvement of sorghum and millets in the dryland under limited moisture. Strategies used in improvement of sorghum and millet to escape moisture stress experienced in these areas are reported. Emphasis in this paper is on research done on improvement of sorghum and millets for human food which was started in 1978. Since then, investigations have been continued on various aspects of sorghum and millet improvement, production, processing and utilisation. Results show that early maturing sorghum genotypes flower in about 65 days at lower altitude (Kampi-Ya-Mawe, 1125 m) and in about 72 days at medium altitude (Katumani, 1600 m). Early maturing pearl millet flowers in about 55 ± 5 days at Kampi-Ya-Mawe and 60 ± 5 days at Katumani. Early maturing finger foxtail and proso millet genotypes take 100 days, 115 days and (65 – 70) days respectively.

Introduction

Kenya land mass is 569,260 Km^2. About 72% is arid, 13% is semi-arid (drylands), 12% is arable with high agricultural potential and 3% forested (Potter, 1983). Sorghum and millets are grown for subsistence by small holders living in the drylands. The area under these crops has been declining (Rutto, 1982; M'Ragwa and Kanyenji, 1985; M'Ragwa et al., 1986). For instance, FAO (1984) estimated that the area under sorghum in 1981, 1982 and 1983 was 210,000 ha., 120,000 ha. and 170,000 ha. respectively. The area under millets in 1977, 1981, 1982 and 1983 was 73,000 ha., 82,000 ha., 45,000 ha. and 50,000 ha. respectively; 52% of sorghum is grown in Nyanza, 23% each grown in Western and Eastern and about 2% in North Eastern, Rift Valley, Coast and Central Provinces. About 95% of pearl millet is grown in Eastern and Rift Valley, 29% of finger millet is grown in Western, 15% in Nyanza and 13% in Rift Valley provinces.

The area, production and yields for 1982 sorghum and millet in the drylands, are presented in Table 1. Sorghum and millet production (1884 t/ha and 1507 t/ha) respectively, are low when compared with that of maize (66987 t/ha). Sorghum and millet yields (535 and 415) kg/ha respectively were also low. Sorghum yields are estimated at 1-0 to 1-5 t/ha in Western province and 0.5 to 1.0 t/ha in other areas. Pearl millet yields were estimated at 0.4 – 0.6 t/ha and finger millet yields were about 0.5 – 0.9 t/ha.

The decline in area, production and yields show that the crops are not preferred in the drylands even though they have many advantages over maize. However, farmers are migrating to these areas due to lack of

Table 1 1982 Area (000 ha), Production[2] (000 tons) and Yield[3] (Kg/ha) of Principal Cereal Crops Grown in Selected Districts at Coast, Eastern and Rift Valley Provinces.

		Maize			Sorghum			Millets		
Province	District	1	2	3	1	2	3	1	2	3
Coast	Kwale	11.38	5.33	468	0.14	0.11	786	—	—	—
	Kilifi	26.45	15.34	580	0.09	0.03	333	—	—	—
	Lamu	2.11	10.36	3560	0.19	0.10	526	0.16	0.06	375
	Tana River	2.65	4.51	1702	—	—	—	—	—	—
	Taita/Taveta	8.18	7.29	891	0.10	0.08	800	—	—	—
	Total	51.57	42.83	—	0.52	0.32	—	0.16	0.06	
Eastern	Machakos	148.0	188.33	1273	4.06	3.06	754	0.799	0.418	523
	Kitui	64.06	50.03	781	23.25	9.66	415	26.99	9.54	368
	Embu	54.75	66.19	1209	6.99	5.4	773	6.39	3.71	581
	Maru	90.70	151.02	1665	6.6	4.158	630	2.2	1.386	630
	Total	357.51	455.57		40.9	22.278		36.389	15.454	
Rift Valley	Kajiado	9.36	14.06	15.02	—	—	—	—	—	—
	Naroko	15.03	33.82	2250	0.005	0.005	1000	0.25	0.23	920
	Jakuru	4.58	14.43	3151	—	—	—	—	—	—
	Laikipia	98.7	34.49	349	0.025	0.011	440	—	—	—
	Baringo	12.6	34.02	2700	0.35	0.38	1086	2.5	1.13	452
	W. Pokot	12.95	40.65	3139	—	—	—	—	—	—
	Total	153.22	171.47		0.38	0.396		2.75	1.36	—
GRAND TOTAL		562.3	669.87	—	41.8	22.994		39.299	15.514	
Average Yield				1191			582			522

[1] Annual Report Ministry of Agriculture (1983), and Annual Report Ministry of Agriculture (Eastern Province, 1982).

Table 2 Monthly and Annual Rainfall Averages from Stations in Agroecological Zones 4 and 5 in Coast, Eastern, and Rift Valley Provinces

Province/ District	Agrieco zone	Station name	ID no.	Altitude, m	Average annual rainfall, mm	Average monthly rainfall, mm											
						Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coast																	
Kwale	5	Kinango	9439015	305	841	20	33	52	146	150	55	58	49	39	84	105	50
Kilifi	5	Baricho	9339027	67	725	33	18	58	98	91	44	30	27	47	77	113	89
Lamu	4	Faza	9241000	8	865	5	2	16	122	276	162	81	45	45	42	45	24
S. E. Tana R.	5	Ngao	9240004	15	704	15	9	25	95	108	67	44	41	102	73	85	40
T. Taveta	5	Voi	9338001	560	587	32	70	81	93	29	7	3	8	15	28	99	122
Eastern																	
Machakos	4	Katumani	9137089	1600	701	55	42	84	145	68	9	6	6	4	29	160	93
Kitui	5	Ikuthe	9238006	732	648	27	30	95	130	15	4	1	2	4	27	201	112
Embu	5	Machanga	9037104	1219	832	35	25	102	161	85	6	3	4	24	85	213	89
Meru	5	Marimanti	9037160	610	879	19	33	79	268	97	10	2	1	3	88	225	54
Rift Valley																	
Kajiado	4	Rombo	9337094	1120	775	54	63	115	152	33	7	5	22	15	53	165	91
Narok	5	Narok Met.	9135001	1890	759	72	74	90	154	96	32	17	24	28	24	69	79
Nakuru	5	Naivasha D.O.	9036002	1900	635	25	40	51	123	76	41	35	44	46	53	63	38
Laikipia	5	Nanyuki	8936045	1790	732	14	31	48	144	90	41	54	76	39	69	82	44
Baringo	5	Perkerra	8935163	1066	654	41	23	62	70	83	52	77	66	37	36	47	40
W. Pokot	5	Sebit	8835027	1311	740	20	34	57	157	101	50	94	36	52	54	49	36

agricultural land in high agricultural potential areas and therefore they would need suitable crops for drylands.

Presently, research on various dryland crops is conducted at National Dryland Farming Research Station (NDFRS), Katumani and its test stations (Kampi-Ya-Mawe, Ithookwe and Perkerra). Rainfall pattern in most drylands is bimodal except in areas like Lanet and Perkerra which have monomodal patterns (Table 2).

Rainfall pattern, reliability and effectiveness for Katumani and Kampi-Ya-Mawe stations have been classified using Braun's (1977) scheme (Table 3). Katumani is classified at the dry end of zone IV and Kampi-Ya-Mawe is at the wet end of zone V where the boundary lies within a P/Eo ratio of 37%. The mean annual rainfall over the 27 years period at Katumani is 701 mm. Table 4 presents monthly high, low and mean rainfall figures, which help to clarify the pattern and show the magnitude of the short term duration (Stewart et al., 1984). Whiteman (1980) categorized the average effective rainfall season length during short rains as 40 and 45 days at Katumani and Kampi-Ya-Mawe respectively. The average season length during long rains is 46 and 35 days at Katumani and Kampi-Ya-Mawe respectively. The seasons are short and the duration of each is 60 days with rainfall peaks in November and April. Rainfall comes in surges of 3-10 days followed by 1 or 2 weeks dry spells. The duration and time when the dry spells occur are the most critical to the crop being developed for semi-arid Kenya.

Dry spells cause injury to millet if they occur during seedling establishment and at post flowering stages. Whiteman (1980) estimated that millet maturity alters about 0.65 days for every month of growth and short rains crop take 5% less time to mature than long rains crop. Studies on rainfall

Table 3 Characterisation of the Seasons at Katumani and Kampi-Ya-Mawe; using Braun's (1977) method

	Short Rains		Long Rains	
	Katumani	Kampi-Ya-Mawe	Katumani	Kampi-Ya-Mawe
Rainfall (mm) (P)	310	354	296	273
Evaporation (mm) (Eo)	506	496	402	450
Probability P. 0.67 Eo	666	54	48	64
Probability P 0.5 Eo	42	30	30	23
Annual P/Eo Ration (%)	38	3		
Ecological Zone	IV	V		

Source Whiteman (1980) Sorghum and Millet Agronomy Investigations in Eastern Province: At NDFRS (Katumani)

Table 4 Katumani Monthly Rainfall Means and 27 year Recorded Extremes (mm)

	Oct	Nov	Dec.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	38	158	90	50	43	86	144	67	9	5	4	8
Low	0	27	12	0	0	0	20	4	0	0	0	0
High	183	487	267	203	177	229	315	151	35	37	20	43

pattern, reliability and intensity, phenological studies and the tours around the drylands helped in planning selection criteria and crop production strategies to be used when developing sorghum and millets for the drylands.

This paper briefly outlines the strategies for improvement of sorghum and millets, the achievements and future research areas in the drylands of Kenya.

Sorghum Improvement Programme

The programme was initiated in 1978 when the government directed a broader emphasis to promote sorghum and millet for human consumption in areas marginal for wheat, maize and rice, otherwise work on this crop for annual feed was still going on at Lanet. The programme emphasises self-reliance and alleviation of poverty with Agricultural Sector giving increasing attention to the marginally rainfed areas, where a rapidly increasing population is faced with diminishing food resources.

Objectives

i To develop and identify sorghum varieties and hybrids for important ecological zones with emphasis on cultivar stability, appropriate maturity, tolerance to diseases and pests good food quality.

ii To develop appropriate production technology defining target areas for sorghum and practices, to optimize use of soil moisture, reduce risk, stabilize production, minimize cost and accommodate the technological, social and economic constraints of small scale farmers.

iii Develop methods of processing at village level for human consumption of brown tannin containing sorghums which are less damaged by birds, undertake quality studies on processing and utilization of sorghum, improve on food forms of the crop and enhance market demand.

iv Disseminate results through training and on-farm testing in collaboration with the extension services in target areas. The progress made in different areas of research will now be explained.

Germ plasm

Surveys throughout the sorghum growing areas revealed that local single season white varieties exist in Turkana, Northern Kitui, Tharaka (Lower Meru) and Ishiara (Lower Embu). The races occuring were Kafir, Candatum, Guinea and Durra. Over 600 genotypes were collected, during the first survey. The last expedition covered the western part of the country and the coastal in 1984 and over 200 genotypes were collected.

There are over 1,600 different sorghum genotypes in the station although some of these may be in a poor state. The genetic variability is very wide due to rich local material and the introduction from different parts of the world. In general the range of 50% flowering is from 45 days to 100 days and height ranges from 1.0 m to 2.5 m.

Other variations are:

i. a) Red grain without testa
b) Red grain with testa
ii. a) White hard endosperm without testa

b) white soft endosperm without testa
c) white with testa
d) white grain and sweet at milk stage
iii. a) yellow endosperm without testa
b) yellow endosperm and sweet
iv. Very early sorghum (maturity range – 60 days.)
v. Local late material (maturity range 140 – 180 days) with shootfly resistance.

Introductions of exotic materials at various levels were received from different programmes for evaluation in Kenyan climatic conditions; the leading contributors are:

i. ICRISAT
ii. Texas A&M University
iii. Indian programme
iv. Ethiopian programme
v. CIMMYT (for cold tolerant)

Some were received directly as cooperation trials especially from the Eastern African regional trial through SAFGRAD or as requisition by the breeder.

Both local or introduction materials were put into observation nurseries for screening at several locations. This was necessary in order to evaluate the potential of the material from different sources, appreciate the specific problems for each ecozone tested and rationalize the varietal recommendation on a broad zonal basis. The major selection criteria used were:

i. Days to anthesis
ii. reaction to stress
iii. food quality
iv. ratooning potential
v. yield.

Other general characteristics sought included good plant type, wide adaptation and stable yield, tolerance or escape features to drought stress and tolerance to diseases and pests including birds.

Only materials flowering in 65 days at Kampi-Ya-Mawe (1,125 m) (a test site in zone IV) and in 72 days at Katumani (1600 m) were retained for semi-arid areas. Many of the local genotypes were late for these conditions and only those with other desired characters such as pest and disease tolerance and drought stress/tolerance were retained for use in the crossing nurseries.

The material selected was grown in a range of trials at several locations simultaneously to represent a range of environments. The main test locations were confined to ecological zone III and IV in order to minimize the risk due to rain failure. The drier ecologies were represented through cooperative programmes established with other organizations.

The relationship between maturity and yield were found to be positive. Therefore it become necessary to stratify the varieties by maturity groups and later relate the recommendations to the rainfall probability for each area.

In 1978-79, a population using MS_3 was established and materials evaluated for drought tolerance using a line-source method were incooporated. The populations provided several useful selections with good plant type and good grain for the pedigree program. During the 1983 short rains, over 1800 introductions from ICRISAT and Ethiopian programme were received through SAFGRAD and screened. Of these, only 9 entries were selected and have been included in the National Varieties performance and should be ready for release in the next three seasons. The program has pre-released the following varieties.

i. *2KX – 17*
This is a short variety (1 m), with a strong stem and broad leaves. Flowers in 68 days, has large head semi-loose with big white grain without testa. The glumes are white, it attains physiological maturity in 95 – 105 days. Its yield potential is 3,000 kg/ha (3 ton/ha). It is recommended for medium to high altitude 1300 – 1500 m in ecozones III and IV where rainfall is 300 mm per crop cycle; a population of 4 to 5 plants per square meter is recommended.

ii. *IS76 T_1 #23*
Medium in height (1.2 m), flowers in 65 days, medium compact head, semi-hard white grains without testa, turns purple on injury, matures in 95 days. Its pigmented glumes sometimes cause grain stain, its yield potential is 3000 kg/ha. It is recommended for lowland to medium altitude (1000 – 1300 m) in zones IV where rainfall is 250 – 300 mm per season. It has good ratooning ability, good food and processing qualities.

iii. *NES 7360*
Medium in height (1.2 m) flowers in 65 days, semi-compact long head with hard white grain without testa. The grains in dark glumes with awns and matures in 90 – 100 days. Recommended for release in similar areas as for IS76 T_1 #23. Yields (2,000 kg/ha or 2 ton/ha) lower than the other varieties but has acceptable ugali and uji qualities and yields over 85% recovery when processed in PRL/RIIC dehuller. It ratoons well.

iv. *IS 8595*
Medium tall (1.5 m), flowers in 68 days, has large semi-compact head with semi-hard white grains without testa. Grains enclosed by the glumes and matures in 95 – 110 days. Yields (1800 kg/ha) low but its long glumes enclosing the grain sometime hides the rain from being seen by birds. Very sensitive to low temperatures which induce sterility and therefore poor seed setting. Recommended for low altitudes (below 1000 m) in Eastern, Coast and Rift Valley Provinces with 200 – 300 mm of rainfall per season. Does well in areas of high night and day temperatures. Recommended plant populations 7 – 8 plants per square metre. Good ratooning ability.

v. *954063*
Dwarf variety (1 m), flowering in 68 days, large compact head with semi-hard white grains without testa. Matures in 90 days, its yield potential is 3000 kg/ha or 3 tons/ha. Higher drought escaping ability than the other recommended varieties.

vi. *954066*
Tall variety (1.5 m), big white grain, red testa below the white pericap. Head semi-compact, flowers in 62 days and matures in 90 days. It is recommended for lowlands with low rainfall expectations e.g. Turkana, Lower Embu and Lower Meru, and Kitui – (600 m). Yield potential 1800 kg ha.

The following varieties are new elite lines:
83369, 83570, 83457, 83628, 83395, 83620, 83386, 83487, 83554 have

given good performance and some of them may be available for pre-release by 1988.

Table 5 gives the environmental X genotype interaction. Fifteen varieties were planted at two sites. One at Katumani 1600 m and the other at Marimanti 630 m. The nature of rainfall distribution was the same, and the amount per season differences was not significant but the effective rainfall was very different due to high evaporation rate at Marimanti. Post flowering drought tolerance is required for Marimanti, while pre-flowering (early at seedling establishment) is of great importance.

Table 5 Comparisons of Performances of Hybrids and best varieties during 1980 short rain at Katumani and Kampi-Ya-Mawe

No. of Entries	Yield kg/ha at Katumani	Performance as a % of variety	Yield in kg/ha at Kami-Ya-Mawe	Yield as % of variety
33 Varieties	3175	100%	2495	100%
33 Hybrids	4063	128%	4685	185%
Best Variety	4193	100%	4056	100%
Best Hybrid	6751	161%	6258	154%
Rainfall over crop life		232 mm		312 mm
Total rainfall over season		260 mm		402 mm

Hybrids

In view of the potentials of the hybrids reported by EAAFRO and the readily available material both from Serere stock and international source, an hybrid development programme for the semi-arid areas was started. The three serere hybrids were not entirely satisfactory in the dry parts of Kenya. The outstanding early hybrid – Hijack was brown-grained while the other two white grained Himidi and Hibred were slightly late maturing for the semi-arid ecologies. After this finding, the programme set to produce its own hybrid. A total of 242 pairs of cytoplasmic male sterile (A-lines) and maintainer (B-line) were evaluated, 72 lines that were well adapted, short with white or yellow grains were identified, these were later reduced to 24. Based on their performance, their wide adaptation, good yields and ratooning properties, some eight R lines were retained, these were:

Ye 67, FX430, LULU-D, 2KX71/3, 2KX/7sk, 954063, 2KX-17, 2KX-17/6.

The hybrids give 50 – 60% better yields than the best varieties under similar conditions in the semi-arids.

It can be said that these trials are a clear proof that hybrid sorghum could be developed with over 50% yield advantage over local varieties.

The sorghum hybrid programme was suspended in favour of varieties due to cost of seed to the farmers.

Ratooning Ability Studies

For the bimodal rainfall areas, the ratooning strategy had to be exploited because of the many advantages. It was found that the dry period between the short rain (October – December) and long-rain (March – June) was 30 – 35 days and rarely exceeded 50 days. The ratoon crop flowered 16 – 25 days earlier than a flesh sown crop, there-by escaping the low temperatures occuring in the months of June – July. Ratoon crop provided ground cover, avoided the labour peak at the start of the long rains and cost for resowing.

Ratoon crop yields in 1980 long rains and 1981 long rains at Kitui exceeded the main crop yields by 45%. It escaped shootfly attack by fast growth rate.

Agronomy

Studies were concentrated in the following areas

i. The influence of residual moisture through choice of crop sequence involving fallow or partial fallow.
ii. Stand establishment time and methods of sowing especially the risk attached to dry planting.
iii. The influence of the plant density and arrangement of the crop.
iv. Management factors affecting the performance of the ratoon crop in sorghum.

The nature and level of treatment were based on the assumption that minimising risk was more relevant to the farmer than maximising yields.

The behaviour of the rainfall within a season was studied and grouped, it was realized that 50% of the rain fell on 15% of rainfall occasions, mostly in the first 30 days of the season. Because crops were growing near their lower level of water tolerance, there were marked yield responses to slight variations above or below the average. This created a dilemma about the type of season to set management levels. For example, if the wet seasons are exploited through high populations of longer maturing crop with fertilizer, this will increase the chances of crop failure when a dry season sets in, but if dry seasons is catered for, considerable potential is lost if a wet season is experienced.

Research Findings:

Moisture could be stored in the soil profile from one short rainy season until the next when it buffered the supply of moisture to crops. The amount of moisture that could be carried over depended on whether the previous recharge season was a bare fallow, partially or fully cropped, the amount of rainfall received and the management of the fallow. The response to residual moisture depended on the current rainy season, on time of sowing and the use of a deep rooted crop. On the basis of these results and reference to other work, it was concluded that:

i. In a third of the 10 seasons, there was a marked response to fallow which would eliminate crop failure in all but 5% of the seasons.
ii. In only 20% of the occasions there was no response to fallow (when there are two consecutive very dry seasons).

Date of Sowing

The onset of rainfall fractuated considerably in these zones; but working on average normal seasons, it was established that there was a low risk to dry sowing provided it was not done before certain trigger dates. These were 20th October for the short rains and 1st March in long rains in areas above 1300 m but 10th March at areas below 1300 m.

Method of Planting

Drilling along the farrow was most convenient, it enabled thinning to the right plant population without hurting the remaining plants. When drilling was done behind an oxen-drawn plough, seeds were placed on the farrow avoiding the deepest part. When dripling was done, (hill planting), thinning should be done as early as possible to minimize competition. When plants were not sown to the right spacing, more than one plant (2-3 plants) was left per hill to build up the required plant population.

Ratoon Studies

Ratoon studies have indicated the basis of survival and performance, the strategy is expected to be especially useful where the long rains were poor (which is often) or temperatures were too low. It was noted that ratoon crop especially over long rains has an advantage over fresh sowing, since, it was early and avoided the cold temperatures associated with this season.

Water Stress Studies

There was a need for sorghum that matures in not less than 100 days for the 25% of the seasons where rainfall below 200 m is expected. Cold tolerance is required in sorghum when grown above 1500 m in the short rain and above 1200 m in long rains. Low temperatures were found to retard sorghum growth rate and to affect the pollination and therefore seed setting.

Sorghum Population Studies

Optimum sorghum populations were established in the range of 4-8 plants/m^2 according to the maturity of the variety, amount of residual moisture in the profile at planting time and the standard of moisture conserving husbandry practised.

Within the plant population range given, arrangement (row width) was at the convenience of the farmer, wide row 120 cm – 150 cm was beneficial in the dry seasons and increased both chances of water availability to the crop and sequential cropping option in the current and following seasons, as well as producing a high proportion of plump grains. The recommended populations had a safety factor to increase the reliability in dry season. Wide row provided advantage in leaving moisture reserves in the soil profile for post-flowering growth and development inspite of the increased advection of the bare soil.

The wider spacing would suit the common methods of weeding which involves use of oxen-drawn plough. It would also allow relay sowing of an early maturing pulse if by mid-season the rains have been good to permit intercropping with pigeon peas. A wide range of populations between 40,000 and 80,000 plants per hectare were recommended to cater for each ecozone and the expected rainfall regimes. the interim recommendation for Serena type of sorghum (maturity period 120 days during long rain) at 1600 m is that a population of 60,000 plants per hectare should be optimum under conditions of good moisture conservation husbandry.

Although plant population was the over-all determinant of the rate at which moisture was removed, the wide row spacing at the highest population had more moisture available to the crop at any particular time, than the low population at the close spacing. This indicated the real effect of row spacing on the pattern of moisture removed. At close spacing, the roots, at any given time, were removing more moisture from greater depth than the corresponding population at the wide spacing.

Yield in Relation to Population

Yields increased with decreasing population at both spacings. The response being greater at the wide row spacing; the highest treatment yield was at the lowest population (41,000 P/ha) at a row width of 120 cm. Negative response to nitrogen at higher population and close rows was observed. A trial of P x N interaction was significant indicating that response to nitrogen was limited by lack of moisture. It was observed that there was less shrivelled grain and lodging at harvest in low population and wide rows. Although there were no significant yield differences due to spacing, grain weight was significantly affected.

Tillage in Relation to Plant Population

Although fewer tillers were formed at high population, they were proportionally less effective in producing grain. There were less tillers at wide spacing, but they produced relatively more grains per tiller and represent an important early formed yield component. In other words, the increase in plants at higher population densities did not compensate for the associated reduction in tiller numbers.

Off Station On-Farm Work

There was a major off station on-farm activity in the 1980 short rains. These rains were below average with most sites receiving between 180 – 230 mm of rain or an amount than could be expected in 25% of the season.

The trials demonstrated the benefit of sorghum as a crop over maize to the farmers. The maize in these zones produced a poor crop or failed. On 82% of the tests, maize was out-yielded by Sorghum. In observation plots and production plots, yields varied from (1-2) tons/ha. On-farm work has been resumed and more information is expected in near future.

Millet Program

This program was started in the 1978 Long rains (M'Ragwa, 1981). During the 1978 – 1985 period, evaluation and yield trials were conducted on four millet species, namely, pearl millet (*Pennisetum typhoides* (Burm) S&H), finger millet (*Eleusine coracana* (L.) Gaertn.), foxtail millet (*Setaria italica*

(L.) Beauv.) and proso millet (*Panicum miliaceum* L.). Presently, emphasis is on improvement of pearl millet, which is the major millet species grown in the drylands.

The aim is to develop, 85 – 95 days maturing pearl millet varieties, composites or synthetics, with wide adaptation and stable yields, free from diseases like rust, ergot, smut and downy mildew, pests and are drought tolerant. Other objectives include development of finger millet, foxtail millet and proso millet varieties maturing in 100, 115 and (60 – 80) days respectively.

Pearl Millet

During period 1978 – 1985, more than 700 local and exotic accessions were screened at Katumani and Kampi-Ya-Mawe. The initial pearl millet collections included 25 and 62 ex-serere composites and lines respectively, as 6 local lines/cultivars.

These were evaluated in 1978 long rain at Katumani and Kampi-Ya-Mawe. This nursery and a tour of the sorghum and millet growing areas helped in identifying the problems and in formulating research strategies for improving these crops. Denton *et al.* (1978) made sorghum and millets local collections consisting of 602 sorghum, 48 pearl millet and 263 finger millet. Wood and M'Ragwa (1980) made more local collections consisting of 34 sorghums, 63 pearl millet, 38 finger millet, 17 foxtail millet and 2 proso millet. During 1983, M'Ragwa made 66 lines/population, and during the 1979 – 1985 period, introductions were received from ICRISAT and India. These were evaluated at Katumani, Kampi-Ya-Mawe, Matuga, Ithookwe and Murinduko. In 1983 short rains, 253 accessions were evaluated and described at Katumani.

These accessions were compared and their worthiness as future sources of breeding stocks was determined. Observations on this germplasm revealed enormous genetic variability for days to 50% bloom, plant type, height, number of productive tillers, spike length, bristle length, seed setting ability, 1000 seed weight and grain yields. They were arranged into 3 plant height groups. The groups were, (a) less than 100 cm tall, (b) between 101 and 160 cm tall and (c) taller than 161 cm. Within each group, the accessions were re-arranged as early or late flowering. The early flowering took (60 ± 5 or 55 ± 5) days at Katumani and Kampi-Ya-Mawe respectively. The late flowering took more than 71 or 61 days) at Katumani and Kampi-Ya-Mawe respectively. Late and very early materials had very poor seed setting and ex-Serere materials performed better than most local cultivars. Early flowering materials were selected and directly advanced into yield trials or used in crossing program. Late flowering materials with desirable attributes were used in the crossing program.

Evaluation and yield trials were conducted during 1978-1985. Observations made from these nurseries and trials revealed that most local lines/cultivars were flowering in about 55 days at Kampi-Ya-Mawe, that is 5 days later than most ex-Serere bred genotypes. They were adapted but tall with variable plant and head types, poor seed setting and variable grain yield which ranged between 182 and 3244 kg/ha (Table 7). All late maturing stocks showed poor seed setting and subsequently low grain yield. The extra early materials also showed poor seed setting and low grain yields. Millets planted in low altitude and warm test sites flowered early and had good seed set and higher grain yields than the materials planted at Katumani (1600 m).

Table 6 Environmental Effect on Sorghum Maturity and Yield

Identification	Marimanti (Lower Meru. 630 m.)				Katumani 1600 m.			
	Days to 50% flowering	Rank	Yield kg/ha.	Rank	Days to 50% flowering	Rank	Yield kg/ha	Ranks
1. Melkamash 79	55	6	585.3	13	94	11	1366.0	11
2. Gambella	56	7	1052.7	2	81	5	2317.3	2
3. 76 T_1 #23	50	1	587.96	12	78	3	1957.0	4
4. MY 146	55	6	831.9	8	72	1	1040.8	14
5. Badoa Local	54	5	817.76	9	84	6	1496.0	9
6. Gross 60:6	52	3	780.4	10	74	2	1938.6	5
7. P – 898012	51	2	543.3	14	74	2	6240	15
8. P – 967083	56	7	859.2	7	84	6	1863.7	6
9. 5 DX 135/13/1/3/1	53	4	1153.63	1	81	5	1320.0	12
10. ICSV 83487 KYSF	58	8	682.2	11	99	2	2261.3	3
11. ICSV 83570 KYSF	52	3	943.9	5	85	7	1173.3	13
12. ICSV 83386 KYSF	55	6	873.2	6	90	10	1372.8	10
13. ICSV 83620 KYSF	54	5	970.2	4	89	9	1860.0	7
14. ICSV 83628 KYSF	55	6	486.5	15	88	8	5643.7	1
15. Check NES 7360	52	3	1034.6	3	79	4	1693.0	8
X	50.5		813.5		88.3		2569.5	

Table 7 Average Performance of some Pearl Millet Genotypes for Days to 50% Bloom and Grain yield: Grown at Katumani and Kampi-Ya-Mawe during 1978

Genotype	Katumani		Kampi-Ya-Mawe	
	Days to 50% bloom	Grain yield kg/ha.	Days to 50% bloom	Grain yield kg/ha.
COMPOSITES				
Serere Composite 1 (SC1)	61	1236	50	1275
SC2	56	2124	49	2825
SC4	68	287	49	958
SC4	64	303	54	855
SC5	59	2088	56	1681
SC6	59	2088	56	1537
SC13	75	732	67	825
SC14	68	997	57	911
Local Line Check	57	209	49	1358
Nursery Mean (n=27)	63	1049.0	47	1558
SE ±	1.2	201.73	0.8	228.6
CV %	9.7	—	6.5	—
LINES				
Serere 2A (S2A)	58	1191	49	1662
S3A	58	858	47	673
S6A	57	1417	46	1799
S17	63	1280	53	1575
S30	68	578	56	787
S33	84	693	68	810
S37	68	164	57	1185
S38	68	450	54	158
Local Line Check	58	333	50	400
Nursery Mean (n=67)	64	768.7	50	1572
SE ±	0.91	93.7	0.62	131.5
CV %	11.7	—	10.2	—
Local Lines				
KC/78-77			52	1067
KC/78-80			56	1391
KC/78-108			59	1311
KC/78-116			57	2844
KC/78-117			62	676
KC/78-119			54	3244
KC/78-120			57	2613
KC/78-154			65	182
SC2			52	2800
Nursery Mean (n=70)			57	2223
SE ±			0.37	265.9
CV %			5.42	321

Table 8 Comparison of Original SC2 (Co) and Improved SC2 (C_1)

	Grain yield kg/ha	Percent change	Days to 50% bloom	Percent change	Plant height cm	Percent change
C_1	16		53.3		199	
C_2	25	56.25	52	+2.4	203	2.0

During these tests, Serere Composite 2 (SC2) and Serere 6A (S6A) showed consistently superior performance to other materials. These were then selected for population improvement by mass selection and recurrent selection. SC2 showed sufficient genetic variability for height and yield improvement by recurrent selection. Its yield potential is 2800 kg/ha. Comparisons of the original SC2 (Co) and improved SC2 (C_1) showed that there was 56.25% gain in grain yield from 1.6 ton/ha to 2.5 tons/ha (Table 8). Response to selection in grain yield in SC2 could be possible and maintained in future cycles of recurrent selection because it retained a high genetic variability for yield after the first cycle of selection (M'Ragwa, 1985). Other promising lines were Serere 6A, Serere 2A, Serere 3A, Serere 17, SC1, SC13, SC5, KC/178-119, KC/78-120, KC/78-125, WC/C75, IVS-5454, IVS P77, ICMC 7803 and ICMS-7819.

Finger Millet

During 1978-1981, over 1500 accessions (local and exotic) were evaluated at Kakamega. The materials were arranged into maturity groups, either early (short) duration or mid-late or late. Each group was then passed to an appropriate site for further screening.

All short (early) duration materials, that is those maturing in (100-115) days were sent to NDFRS, Katumani. During these tests conducted at Katumani, Ithokwe (Kitui), Kampi-Ya-Mawe and Murinduko, a local line showed promising performance and was selected for further purification by mass selection. This line Ekalakala I (collected in Machakos) had yields of about 1400 kg/ha under rainfall of 200 mm in 1980 long rain. Some good Serere cultivars for wetter areas were also selected and advanced in yield trials and some are pre-released for general cultivation in Nyanza, Western and Rift Valley provinces.

Foxtail Millet

This crop is important in lower Meru and lower Embu. Some 470 ex-ICRISAT stocks were evaluated together with the Serere stocks and local collections during 1980. The best entry Ise 285 was recommended for pre-release to the farmers.

Proso Millet

Breeding of proso millet has received little attention. However, ex-ICRISAT and 3 local lines were evaluated at 4 sites. At first, Serere I was selected for its adaptation but later N40101 showed higher yield and better resistance to shootfly than SI. It is now multiplied for general cultivation.

Achievements

Since 1978, the following has been achieved:

i. Development of Katumani Millet Improvement program and the strategies for improvement of these species in semi-arid Kenya.
ii. Collection and description of Millet germplasm.
iii. Identification of strategies and documentation of the research work done on Millets at Katumani and its substations.
iv. Development and release of the following improved millet cultivars (M'Ragwa et al., 1986) to farmers.
   a) Pearl Millet
      1. Katumani Pearl Millet I (KAT/PM-1)
      2. Katumani Pearl Millet 2 (KAT/PM-2)
   b) Finger Millet
      1. Katumani Finger Millet 1 (KAT/FM-1)
      2. GULU E
   c) Foxtail Millet
      1. Ise – 285
   d) Proso Millet
      1. Serere I
      2. N40101

Future Work

i. A thorough sorghum and millet germplasm collection to include wild types and land-races will be done starting in 1986/87 short rains.
ii. The germplasm will be documented, evaluated, described and breeding worthiness of each accession will be determined.
iii. Review of breeding objectives, methods and programs will be done and recommendations will be implemented in October 1986.
iv. Yield tests in appropriate sorghum and millet ecological zones will be strengthened.
v. Sorghum hybridisation program will be started.
vi. Sorghum ratoon ability studies will be started.
vii. Disease (long smut) and pest (stalk borer and shootfly) reactions will be started.
viii. Pearl millet population development will be started.
ix. Physiological studies on drought and pest tolerance using line sprinkler source method will be initiated.
x. Processing and utilisation studies will be continued and strengthened to include millets.

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15 Improvement of maize yield under drought stress

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Summary Throughout the lowland humid tropics unpredictable periods of drought are responsible for significant reductions in maize (*Zea mays* L.) yield. Yield losses may be disastrously large if drought coincides with the period 1-2 weeks before or after flowering, and improvement of resistance to drought during this period will reduce farmer risk.

Plant breeding programs for improved performance of maize under drought concentrate on modifying the plant genotype so that it can escape drought (by increasing the volume of soil water available) or can tolerate low tissue water potentials. Direct measures of these traits are time-consuming, and it has been more effective to select indirectly for escape and tolerance mechanisms, concentrating on rates of tissue elongation, synchronization of male and female flowering, canopy temperature relative to ambient, rate of foliar senescence as well as yield under drought stress.

Full-sib progeny of the tropical lowland white population Tuxpeño were grown under three irrigation regimes in replicated single-row plots 2.5 m in length at a rainfree site as part of a recurrent selection scheme that commenced in 1976. Stress levels were: no stress (normal irrigation), medium stress (irrigation stopped two weeks before anthesis) and severe stress (irrigation stopped 3 weeks after emergence). Yields, on average, were 6.0, 4.0 and 1.5 tons/ha, respectively, under the three levels of stress. The genotype x stress level interaction was significant in the first selection cycle, and a drought resistant synthetic was created from families selected for high and stable yield across levels, for a low degree of leaf death, for synchronizatoin of male and female flowering and for maximum relative rates of elongation. This variety outyielded all others by 0.5 tons/ha under severe water stress, and maintained yield under well watered conditions.

Recurrent selection for performance under drought has been practiced among 250 full-sib progeny in this population for 8 cycles. Canopy temperature, determined by infrared thermometry at flowering, was highly correlated (= 0.73**) with yield under severe stress, and was included in the selection index from cycle 3 onwards.

After three cycles of improvement, evaluation under the same stress levels showed that grain yield increase under severe stress averaged 9.5% per cycle, versus 3% improvement in total dry matter per cycle. Selection improved synchronization of flowering, decreased barrenness under drought stress, appeared to increase rooting depth, but did not affect maturity or grain yield under irrigation. Selection in Tuxpeño for reduced plant height at high density was also effective in improving performance under drought.

Evaluation after 6 cycles of selection at several sites under rainfed conditions, and under the three levels of water stress indicated that the rate of improvement under severe drought stress fell in later cycles. This may indicate that variability for selected traits is diminishing in the population. The need for precise field techniques when selecting for yield under moisture stress is emphasized.

Based on these results, recurrent selection for resistance to drought at CIMMYT is being extended to four new lowland tropical populations (La Posta, Pool 26, Pool 16 and Pool 18). The drought resistant population, Tuxpeño Drought, in combination with sources of the 'latente' genetic system, will be used as the basis of a subtropical pool of drought resistance, which will also serve as a source material for national programs.

Introduction

Global estimates indicate that unpredictable periods of drought occurring within the normal rainy season may account for an average production loss of 15% in tropical areas (Fischer *et al.*, 1983). Christiansen (1982) estimated that production on 26% of the world's 14 billion hectares of arable land is limited by drought stress, and that 85% of global cropland is rainfed.

The absolute duration of growth of annual crops in the tropics is generally set by the length of the wet season. Within the normal rainy season, however, dry periods of two to five weeks, commonly occur in an unpredictable fashion. This is reflected in highly variable rainfalls within any month. An example from two sites in Ghana (Fig. 1) shows that over a 40-year period, minimum monthly rainfall totals were substantially less than potential evapotranspiration (ET_o) in very month, indicating that drought can occur at all stages of the growing season. The 75% probable rainfall totals (that quantity of rainfall equalled or exceeded in 3 years out of 4) exceeded ET_o in only 50% of the growing season at Kumasi and in 35% of the growing season at Tamale, suggesting that the effects of dry spells are felt more at either end of the rainy season. Obviously the severity of drought is accentuated on soils of low water holding capacity, when rooting depth is restricted by compacted or acid subsoils, or when weeds are present.

Annual fluctuations in sub-Sahelian maize production appear to be more affected by regional variations in the timing and total supply of rain than by any other factor. Drought-tolerant varieties provide a highly cost-effective means of reducing fluctuations in regional grain supply in this, and other capital-deficient areas, and can increase stability of year-to-year food production among small-scale farmers.

Drought-sensitive stages in the growth of the maize crop

Maize has two periods in its growth when inadequate moisture availability can disastrously affect final yield. The first is during establishment, when stand can be substantially reduced because of inability of seeds to imbibe water against the gradient of soil water potential. Poor plant stands have been identified as a major constraint to production by small-scale farmers (Akposoe and Edmeades, 1981), who will often attempt to plant as early as possible to reduce the length of the mid-season hunger gap.

Although there is a considerable risk of stand loss from an uncertain start

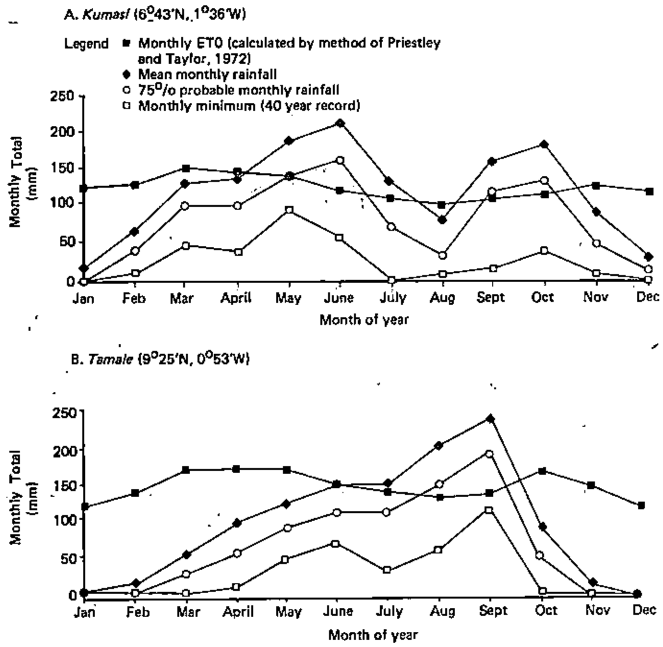

Figure 1 Monthly rainfall characteristics and potential evapotranspiration of two maize growing locations in Ghana. Rainfall data from 40 years of records were used for each site

to the rains, the yield gains from early planting can be considerable (Twumasi-Afriyie and Edmeades, 1982).

The period bracketing flowering is the second major period of sensitivity to moisture deficits (Shaw, 1983). The similarity (Fig. 2) in response of grain yield to moisture stress and to a prolonged period of shading, suggests that general tolerance of reduced photosynthesis per plant from a variety of causes is low during that growth stage when grain numbers per plant are mainly determined. More specific effects of drought at flowering occur because of the extreme sensitivity of cell expansion to water deficits (Boyer and McPherson, 1976; Parsons, 1982). Maize is unusual in that the stigma and pollen tubes must frequently extend, by cell division followed by expansion growth, to 30 cm in length. Disastrous reductions in harvest index and grain yield accompany severe drought at silking (Hall *et al.*, 1981), caused by delayed silk growth and embryo sac abortion following pollination (Moss and Downey, 1971), and sometimes by tassel blasting or pollen dessication.

Aside from these critical periods, maize is drought tolerant, responding to preflowering drought by a reduction in leaf area and height. Drought after flowering induces foliar senescence and can cause extensive remobilizaton of dry matter from the stem and husks to the grain. Lodging often results, and kernel weights will fall, but grain yields rarely drop catastrophically (Boyer and McPherson, 1976). Accordingly it seems sensible to focus attention on events around germination and flowering when considering improvement of drought resistance in maize.

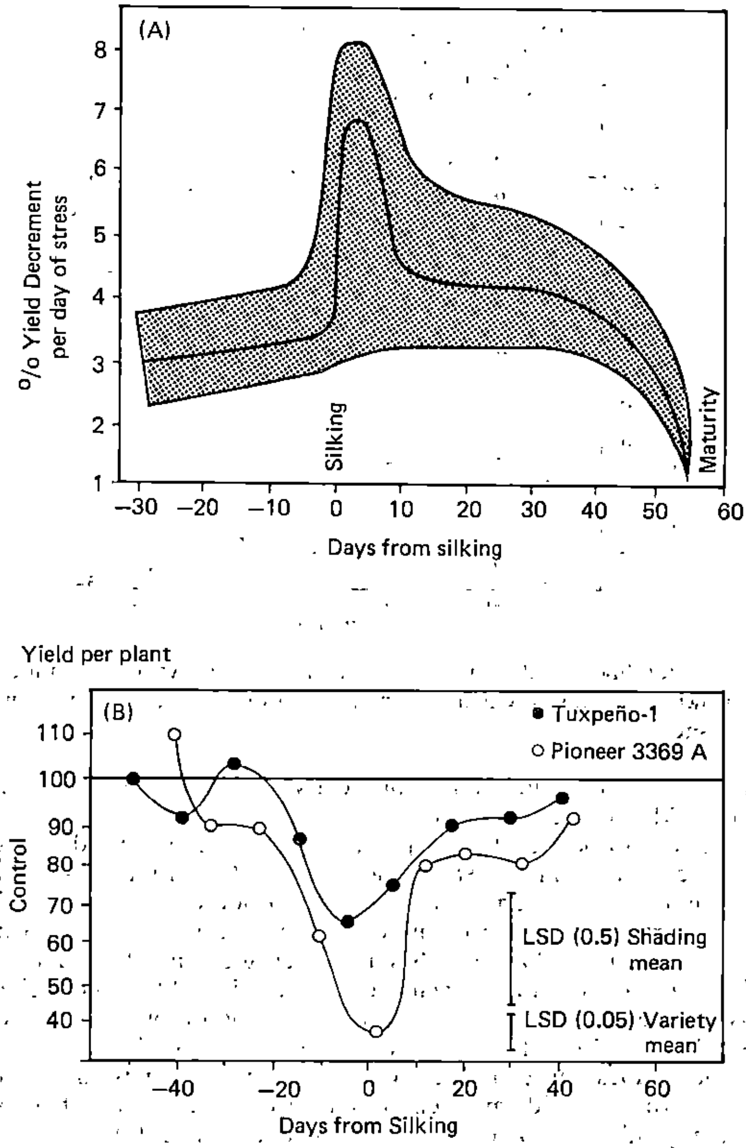

Figure 2 Relationship between days from midsilking and susceptibility of maize yield to (A) one day of moisture stress (Shaw, 1976) and (B) 11 days with 54% shading of the crop at various growth stages (Fischer and Palmer, 1980).

Possible plant strategies leading to improved performance of maize under drought

Grain yield (GY) can be considered as:

$$GY = W \times WUE \times HI$$

(Turner and Begg, 1981)

Where W = total volume of water available for growth (mm)

WUE = water use efficiency (kg dry matter mm^{-1})
HI = harvest index

Faced with insufficient water, plants may either avoid (or escape) drought, endure moisture deficits, or die. Stable crop production requires avoidance (escape through early maturity, conservation of water, or the capacity to maintain turgor under conditions of soil mositure stress) and tolerance of low tissue water potentials (Blum, 1985).

When selection takes place under conditions of stress, heritability for yield, already low, falls further. Selection for yield under these conditions becomes inefficient (Blum, 1982), as field variation in soil water-holding capacity and rooting depth begin to directly affect yield. This means that alternative physiological characteristics associated with drought tolerance must be employed to augment selection for yield. Specific statistical techniques designed to control within-replication environmental variation, such as the use of lattice designs, or the nearest neighbour analysis (Wilkinson *et al.*, 1983), also became important.

A list of potentially useful plant characteristics that could be used in selection for improved performance of maize under drought is given in Table 1.

Selection for morphological or developmental characteristics normally implies drought avoidance. Early maturing varieties will often escape the effects of an early cessation of the rains, though when the timing of mid-season drought is unpredictable, a change in crop maturity is of little value, and will not be considered further here. Maize is, in general, a non-tillering species possessing a single large ear per plant upon which many kernels develop synchronously, and has little scope for drought avoidance through developmental plasticity. A possible exception to this generalization is 'latente' maize, which appears to suspend its development during periods of water stress (Castleberry and Lerette, 1979). Epicuticular wax serves to reduce cuticular transpiration (O'Toole *et al.*, 1979), but variation in wax content in maize is less than in crops such as sorghum. Waxy leaves, leaves that roll to avoid radiation load, and erect leaves that increase the proportion of radiation absorbed in low, more humic canopy layers, normally save only small amounts of water (Seetherama *et al.*, 1982), but when stress is severe, especially during flowering, this can result in significant yield increases.

An increase in rooting depth or rooting intensity, on the other hand, can substantially increase the volume of water available to the plant, but direct measures of root morphology, or studies of water depletion by depth, are time-consuming techniques better suited to selecting parents for crossing than for recurrent selection among progenies within a population.

Physiological traits which can lead to improved performance under drought (Table 1) usually infer drought tolerance. This often equates with tolerance of high leaf temperatures, a capacity to continue metabolic processes despite low tissue water potentials and the ability to rapidly resume normal metabolic activity when stress is lifted. This may be mediated through increased membrane stability, osmotic adjustment, accumulation of metabolites (such as proline) or through changes in hormones such as abscisic acid. Direct selection for these traits is difficult because their measurement is too time-consuming to be employed on a large scale, and the roles of these factors in plant water relations are still unclear.

It is apparent, however, that rapid osmotic adjustment as drought intensity increases, and rapid recovery of metabolic function following

Table 1 Morphological, developmental and physiological traits associated with drought resistance in maize, and their possible use in a breeding program (after Seetherama, et al., 1982)

Character	Mechanism of resistance	Information available	Potential techniques for use in selection/remarks	Prospects for breeding
A: Morphological and Developmental				
1. Maturity	Avoidance	Considerable	Visual (Blum, 1985)	Very good
2. Developmental plasticity	Avoidance/tolerance	Scant	Limited variability within single eared varieties	Low
3. Waxy leaf	Avoidance	Scant	Colourimetic determination of wax (Ebercon et al., 1977; Maiti et al., 1984)	Low
4. Leaf width, angle	Avoidance	Moderate	Visual score, measurement (Blum, 1985)	Moderate
5. Root morphology (deep or intensive rooting)	Avoidance	Scant	Direct: visual, measurement (slow) indirect: water depletion; canopy temperature by infrared thermometry (Hurd, 1974; Blum, 1975)	Low/moderate
6. Root axial resistance	Avoidance	Scant	Measurement (slow) (Passioura, 1982)	Low
7. Leaf rolling	Avoidance	Moderate	Visual score (Jones, 1979)	Fair
B: Physiological				
8. Germination at low soil water potential	Tolerance	Moderate	Artificial osmotica (Johnson and Asay, 1978, Blum et al., 1980)	Low
9. Stomatal control	Tolerance/avoidance	Moderate	Porometry, infrared thermometry (Blum 1975; Fischer et al., 1983)	Good
10. Dessication and heat tolerance	Tolerance	Moderate	Electrolyte leakage (Sullivan and Ross, 1979)	Moderate

Table 1 cont.

Character	Mehanism of resistance	Information available	Potential techniques for use in selection/remarks	Prospects for breeding
11. Osmotic adjustment	Tolerance	Moderate	Psychrometry, pressure volume relationships (slow) (Turner, 1981)	Low
12. Changes in hormone level	Tolerance	Scant	Gas liquid chromatography (Austin et al., 1982)	Low
13. Changes in metabolites	Tolerance	Scant	Gas liquid chromatography (Hanson and Hitz, 1982)	Low
14. Cell enlargement (leaf, stem, silk elongation)	Avoidance	Considerable	Measurement (Fischer et al., 1983)	Good
15. Rate of leaf senescence	Avoidance	Moderate	Visual score; chlorophyll determination (Fischer et al., 1983)	Good
16. Anthesis-silking interval	Avoidance/tolerance	Empirical	Measurement (Dow et al., 1983)	Good
17. Recovery from stress	Tolerance	Moderate	Visual score	Moderate
18. Remobilization of CHO reserves	Avoidance/tolerance	Moderate	Indirect: measured via yield after defoliation (Blum et al., 1983)	Fair
19. Reduced barrenness	Tolerance	Moderate	Measured via yield; prolificacy	Good
20. Yield under stress	Avoidance/tolerance	Good	Measurement	Good

drought are highly desirable characteristics in maize subjected to non-terminal moisture stress. Genetic differences exist among lines for these characters (Turner, 1981; Long, 1974).

Although direct selection on a large scale for tolerance of low tissue water potentials and for the ability of genotypes to acquire more soil water are not feasible at present, indirect selection is possible. Selection may be for increased ability to germinate against an osmotic gradient, high rates of leaf, stem and silk growth, a short anthesis-silking interval, low canopy temperatures relative to ambient, slow rate of leaf senescence, increased quantity of green leaf retained following rewatering, reduced barrenness and high yield under moisture stress. If increased rooting intensity or an improved capacity for osmotic adjustment are of adaptive significance, then the potential exists for both to be improved simultaneously by such indirect selection, provided variation for these traits exist in the population.

The closure of stomata serves to isolate the plant from its dessicating environment, but must be viewed as a solution only to short-term stresses because of the accompanying reduction in carbon fixation. Mid-day stomatal closure and leaf rolling allow photosynthesis to occur when the vapour pressure deficit is smaller, thus increasing water use efficiency; stomata which are sensitive to low water potential are, therefore, desirable under conditions of short-term stress, since this allows rapid recovery when stress is alleviated.

If stress is terminal, less sensitive stomata seem appropriate (Turner, 1982). Direct measurement of stomatal conductance is still a relatively slow procedure; indirect measurements, in which leaf temperature relative to ambient is measured by infrared sensing, are rapid, and when carried out with care offer considerable promise in a crop improvement program.

The rate at which lower leaves senesce under drought stress seems to be a reliable indicator of plant water status and drought tolerance. In some cases drought effects may be reduced by a reduction in transpiring leaf area. With high grain yield as our objective, selection for delayed foliar senescence is generally practiced, since this should identify drought tolerant lines, or those which can locate water sufficient for their needs.

Several traits listed in Table 1 are the results rather than mechanism of drought resistance. The rate of cell enlargement, the level of barrenness, and yield itself can be considered consequences of drought resistance or drought avoidance, but this in no way reduces their value as potential selection criteria. Finally, genotypes which are tolerant of reduced photosynthesis per plant from any stress are likely to be drought-tolerant as well (Dow *et al.*, 1984). Maize with high levels of general stress tolerance will be characterized by a short anthesis-silking interval, prolificacy (Motto and Moll, 1983), small tassel size and erect leaves (Mock and Pearce, 1975).

Selection for Drought Resistance in the Population Tuxpeño

This program has been described in detail elsewhere (Fischer *et al.*, 1982; Fischer *et al.*, 1983; Islam *et al.*, 1985). Blum (1983) suggests that "unidentified drought adaptive alleles exist at relatively high frequency in common breeding populations", and proposes a "judicious incorporation of some physiological work" within the framework of a normal breeding program. The recurrent selection program for drought resistance in the population Tuxpeño, briefly described below, is an example of this approach.

Choice of germplasm and methods of selection

Data derived from the Experimental Variety Trials conducted by CIMMYT in 1973 (CIMMYT, 1974), indicated that the population Tuxpeño Crema I was stable and high yielding across many rainfed sites and it was from Cycle 12 of this population that Tuxpeño Drought was derived. Selection criteria were developed from a variety trial, which included Tuxpeño (Fischer et al., 1983), grown in 1975 at Tlaltizapan (latitude 19N, altitude 940 m). This site receives no appreciable rainfall from October till April; temperatures average 32°C maximum and 12°C minimum, and the soil is a calcareous vertisol 1.5-2.0 m in depth, with a pH of 7.6-7.9.

Initial selections were made among 85 full-sib families grown in two replications in 2.5 m long plots at 53,000 plants ha^{-1} under three levels of water stress. Fertilizer applied in each cycle was 200:80:0 kg ha^{-1} $N:P_2O_5:K_2O$. Stress treatments were: S_1, no stress (normal irrigation); S_2, grain filling stress where normal irrigation was withdrawn from two weeks prior to anthesis until maturity; and S_3, a flowering and grainfilling stress, in which irrigation was withdrawn from tassel initiation until maturity. Analysis of variance of grain yield across stress levels showed a statistically significant genotype by stress level interaction, indicating that significant changes in ranking for yield between stress levels had occurred (Fischer and Edmeades, 1977).

Selection criteria used in the first selection cycle, and subsequently, were:

i. Relative leaf and stem elongation rate (RLE). Here the rate of growth of a newly exposed leaf and the stem was measured over a one week interval. About 20 days prior to midsilking, when plants in the S_3 treatment were showing midafternoon leaf rolling, the tip of the youngest visible leaf in the whorl was cut on 4 plants per plot in the S_1 and S_3 treatments. The height from the ground to the cut tip was measured, and one week later the measurement was repeated. Normally a second set of measurements was initiated immediately, provided tasseling had not commenced. The increment of extension in treatment S_3 was expressed relative to that in treatment S_1 so that RLE was freed from genetic differences in elongation rate under non-stress conditions.

$$RLE = \frac{HS_7 - HS_0}{HI_7 - HI_0} \times 100$$

Where HI_7 = leaf tip height under irrigation at day 7.
HI_0 = leaf tip height under irrigation at day 0.
HS_7 = leaf tip height under stress at day 7.
HS_0 = leaf tip height under stress at day 0.

ii. Anthesis-silking interval (ASI), or the interval between dates of 50% anthesis and 50% silking, was observed by daily counting of these events for all bordered plants within each plot.

iii. Leaf death score (LDS), consisted of a visual rating made about 5 weeks after midsilking and repeated weekly until all leaves were brown. The scale was 1 (almost no leaves dead) to 5 (virtually all leaves dead). Ratings were averaged over the 2 or 3 occasions they were made.

iv. Yield, measured on shelled grain from every plot.

v. From Cycle 4 onwards, canopy temperature, measured with an infrared thermometer* under still, sunny conditions near the middle of the day, at or near midsilking, was added as a fifth selection criterion.

From C_2 onwards, the number of full-sib families evaluated under each stress level was increased to 250, which, with 6 additional checks, comprised a 16x16 simple lattice in replications at each water level.

The selection of superior progeny was performed using a selection index (Schwarzbach, 1976), based on the above criteria. For each character a phenotypic 'target' was set in standard deviation units from the population mean. Distances from the targets for all characters were computed in standard deviation units, and weighted for each character, depending on its relative importance. Correlations among characters were not taken directly into account in the selection index. Examples of selection targets and intensities are shown in Table 2 and correlations between selected characters are listed in Table 3.

The maintenance of plant maturity at the same level from cycle to cycle was considered an important criterion, and time to flower was monitored during progeny selection. Since the intensity of drought stress increased progressively with time, it was relatively more severe for late rather than

Table 2 Statistics for 250 families of Tuxpeño Drought C_3 and for selected families grown at Tlaltizapan 1979-80 under normal irrigation (S_1) and severe stress (S_3) (from Fischer *et al.*, 1983).

	Grain yield (kg ha⁻¹)		Anthesis-Silking Interval (Days)	Relative Leaf and Stem Elongation (%)	Leaf Death Score	Canopy Temperature (°C)
	S_1	S_3	S_3	S_1, S_3	S_3	S_3
Population Statistics						
Mean	5177	1324	5.8	64.6	3.1	28.0
SD	757	428	2.3	8.4	0.7	0.8
CV (%)	14.6	32.3	40.0	18.0	23.0	2.7
Maximum	6865	2918	14.1	9.35	5.0	30.6
Minimum	2638	93	0.1	44.5	0.9	26.2
Selection Index						
Target (SD units from mean)	+2.0	+3.0	−2.0	+2.0	−2.0	−2.0
Weighting	2.0	3.0	2.0	2.0	2.0	2.0
Selections						
10 families	5796	2171	3.2	70.3	2.4	26.8
80 families	5529	1732	4.4	68.5	2.6	27.1
Selection differential for 80 families (%)	+6.8	−30.8	−23.4	+11.0	−26.0	−4.0
SD units	0.46	+0.95	−0.61	+0.45	−1.00	−1.13

* Barnes Instatherm, Model 14-220 0D-4, Barnes Engineering Company, Stamford, Connecticut. Telatemp AG-42, Telatemp Corp, P.O. Box 5160, Fullerton, CA 92635, USA.

Table 3. Linear correlation coefficients between grain yields under non-stress (S_1) and severe stress (s_3) conditions and other characters used in selection in 250 full-sib families of Tuxpeño Drought C_3 when grown at Tlaltizapan 1979-80. (Fischer *et al.*, 1983)

	Grain Yield	
Variable	S_1	S_3
Grain yield (S_3)	0.17*	1.00
Relative leaf and stem elongation rate	−0.15	0.39**
Anthesis-silking interval (S_3)	0.04	−0.36**
Leaf Death score (S_3)	−0.15*	−0.48**
Canopy temperature (S_3) at:		
– 7 days before anthesis	—	−0.56**
– Anthesis	—	−0.73**
– Grain filling	—	−0.65**
total biomass (S_1)	0.64**	0.25**
Harvest index (S_1)	0.07	−0.01

* Significant at p=0.05
** Significant at P=0.01

early flowering families, and there was a tendency for selections to be from the earliest fraction of the population. This was countered by including as a selection target, the population mean of days to 50% anthesis.

Recombination of the superior 25-40% of families to reform the population, and of the superior 4% of families to form experimental varieties, took place during the summer in Poza Rica (latitude 20°N, altitude 60 m) (average maximum and minimum daily temperatures, respectively, 33°c and 22°C). Recombination and the formation of new full-sib families for the next testing cycle occurred in the same step, so that one cycle of selection was completed each year.

Beginning at cycle 5, a set of full-sib families was planted at 50,000 plants ha^{-1} in 11 metre rows at Poza Rica in the winter, while evaluation under drought was occurring at Tlaltizapan. Within-family selection was made for synchronization of anthesis and silking, reduced height, increased leaf angle and other agronomic characters, and plant-to-plant crosses were made between desirable plants. At harvest, 1-3 ears from each progeny were selected for recombination in the succeeding summer cycle.

By 1985, 8 cycles of recurrent full-sib selection in the population Tuxpeño Drought had been completed.

Evaluation of usefulness of physiological traits

Following evaluation of 85 full-sib families under three levels of water stress in 1975-76, four experimental varieties were formed by crossing together 10 selected families in all possible combinations. The bases for selection were:

(i) best for grain yield under non-stress (S_1) conditions.
(ii) best for grain yield under conditions of severe stress (S_3).
(iii) best for the resistant physiological traits (a)-(c) listed on page 203, and high grain yield across stress levels, S_2 and S_3.

(iv) Most susceptible, with lowest values of traits (a)-(c) listed on page 203.

The four synthetics were evaluated under the same three stress levels at Tlaltizapan in 1976-77 (Figure 3). Selection (iii), based on physiological and morphological traits associated with drought tolerance and high mean yield across stress levels, outyielded all other selections by a significant (P=0.05) 0.5 tons/ha under severe stress (Fischer and Edmeades, 1977). This demonstrates the value of physiological traits as aids to selection under conditions when heritability of yield is low.

Selection for yield under severe stress alone produced a variety which performed relatively poorly under non-stress conditions (Fig. 3(A)). This indicates that responsiveness to well watered conditions can be lost, and implies the need to monitor and maintain performance under non-stress conditions whilst improving performance under conditions of stress.

Table 4 Influence of selection for various characters upon yield, yield components, and deep rooting intensity, when selections from Tuxpeño were grown under irrigation (S_1) and drought stress(S_3) at their optimum density. Tlaltizapan, 1981-82 (Fischer *et al.*, 1983)

Character	Cycle	Grain Yield (kg.ha^{-1}) S_1	Grain Yield (kg.ha^{-1}) S_3	Yield change Per Cycle (%) S_1	Yield change Per Cycle (%) S_3	Harvest Index (%) S_3	Ears Per Plant S_3	Root density Score S_3
Drought	0	5859	1224			16.4	0.57	0.84
Resistance	3	6179	1572*	1.8	9.5	20.9	0.65	1.28
	EV[a]	6311	1647			20.8	0.74	1.27
Reduced[b]	6	5276	1129			15.1	0.56	2.02
Plant height	12	5358	1203	1.0	1.1	15.0	0.65	0.96
	15	5893	1718*	1.3	5.8	25.6	0.85	1.21
Reduced	0	5608	1213			15.7	0.58	0.96
Tassel	6	6172	1673*	1.7	6.3	22.2	0.65	1.12
Reduced	0	5608	1213			15.7	0.58	0.96
Leaf	6	6196	1468*	2.1	4.1	24.1	0.73	0.87
Population 21[c]	0	5608	1213			15.7	0.58	0.96
	3	6458	1315	5.0	2.8	15.7	0.56	1.37
LSD (P=0.05)		899	433			2.0	0.13	0.50
CV (%)		11.7	23.8			32.8	16.5	30.0

* Significantly different from original cycle (P=0.05) (preplanned F-test).
[a] Experimental variety (selected from C_2 with 4% selection intensity).
[b] Planting dates arranged so all cycles flowered at or near same time.
[c] Selected for wide adaptation and high yield through International Progeny Test System.

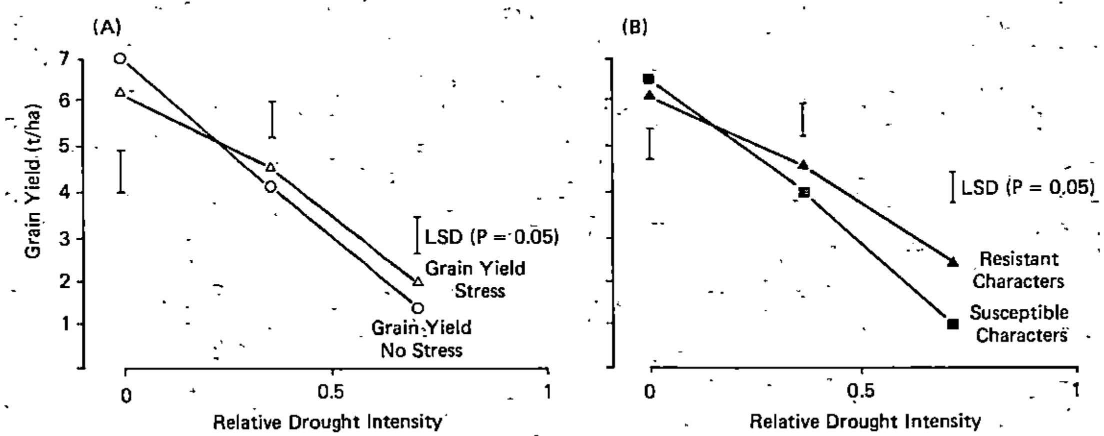

Figure 3 Influence of Moisture Regime on Performance of Four Experimental Varieties of Tuxpeño-1 when Selected for High Grain Yield under No Stress and Stress (A) and for Physiolgical Character for Resistance and Susceptibility to Drought (B) (Fischer et al., 1983)

Evaluation of progress in selection

Following three cycles of selection for improved performance under drought, an evaluation of progress was made at Tlaltizapan in this and in four other versions of the Tuxpeño population. These had undergone selection either for changes in morphology (reduced height; reduced tassel size, reduced leaf area above the ear), or for high yield and broad adaptation in the International Progeny Test System (Paliwal and Sprague, 1981). Selections for reduced plant height had been shown to affect maturity and optimum density for grain yield (Johnson et al., 1986). Planting dates and densities were adjusted to reflect this, and to ensure that flowering occurred at about the same time in these entries. Other varieties were sown on one date and thinned to 53,000 plants ha/^{ha}. Fertilizer applied was 200:80:0 kg/ha $N:P_2O_5:K_2O$. Plot size was 8 rows 5 m in length, and the trial was replicated 4 times at each of the three stress levels. Grain yield (Table 4) under stress improved at 9.5% per cycle in Tuxpeño Drought, the greatest rate of increase of any of the Tuxpeño subpopulations. The experimental variety, derived from a 4% family selection pressure in C_2 of improvement, yielded 4.7% more than did a bulk of C_3 under stress.

All morphological selections showed higher rates of gain in performance under drought stress than Population 21, whose selection was based on international performance of progeny. Best gains came from the reduced height selections in later cycles. It is of interest that increased gains in performance under drought in this population coincided with that period in selection when performance under high plant density (104,000 plants/ha) was being used as a principal selection criterion (Johnson et al., 1986). Changes in yield under drought stress were reflected in a greater number of ears per plant and a higher harvest index (Table 4), and there is some indication, based on a simple score of frequency of roots in soil cores, that the quantity of roots in the lower part of the profile (120-150 cm in depth) had increased.

The improvement in yield under drought stress in morphological selections (designed to increase the proportion of assimilates reaching the ear at flowering time) suggests that considerable improvement in drought resistance in maize can be made by selecting for general tolerance of stresses which reduce photosynthesis per plant at or near flowering. Of these, high plant density, and possibly defoliation, are the easiest to manipulate, and selection for performance under these stresses may concommittantly increase tolerance of drought stress.

During 1984 and 1985 four cycles of selection in Tuxpeño Drought (C_0, C_2, C_4, C_6) and three selections of Population 21 (Tuxpeño 1) based on superior performance across locations from 1974, 1977 and 1981 International Progeny Tests were grown in a number of locations. At Tlaltizapan they were grown in winter under the same three stress levels (S_1, S_2 and S_3) as previously described. At Poza Rica (summer and winter cycles), Tlaltizapan (summer), Veracruz, Mexico (summer), Jutiapa, Guatemala and Pueblo Nuevo, Nicaragua, the trials were grown under rainfed conditions. At each location treatments were replicated 4 times, and a plant density of 53,000 plants/ha was obtained by overplanting and thinning. Fertilizer applied was 200:80:0 kg/ha $N:P_2O_5:K_2O$. At Poza Rica and Tlaltizapan, total above ground biomass was measured, harvest indices calculated and average kernel weights determined from a 1000 grain subsample.

Virtually none of the rain-fed sites experienced drought, and yields from these sites resembled those from Tlaltizapan under non stress conditions

(Table 5). In the winter trials at Tlaltizapan gains per cycle average 2% for treatment S_1, 4.8% for S_2 and 4.0% for S_3. These were lower than those reported by Fischer *et al.*, (1983), but were considerably larger than those observed in experimental varieties derived from the International Progeny Test Program (Table 5). Increased grain yield under stress was related to greater numbers of kernels per plant rather than increased weight per kernel.

Table 5 Grain yield and other characters as influenced by simulated drought in various cycles and varieties of the populations Tuxpeño Drought and Tuxpeño-1 when grown at Tlaltizapan in 1984-5, and at other sites under rainfed conditions. (From Islam et al., 1985).

	Silking Interval (days)	Grain Yield (kg ha^{-1})				Harvest Index	Kernel No m^{-2}	Weight Per kernel (mg)
	S_3[a]	S_1[a]	S_2[a]	S_3[a]	Across Rainfed Locations[+]	S_3[a]	S_3[a]	S_3[a]
Tuxpeño Drought								
C_0	7.1	5882	2502	1642	5143	0.21	800	153
C_2	8.0	5939	3105	1779	4958	0.24	919	146
C_4	7.1	6430	3355	1915	5160	0.24	956	153
C_6	4.5	6595	3224	2041	5157	0.26	978	163
Population 21 (Tuxpeño-1)								
Across 7421	10.7	5783	2419	1472	4532	0.19	724	157
Across 7721	9.4	5389	2691	1478	4939	0.19	753	151
Across 8121	9.9	5310	2471	1422	5124	0.17	530	181
LSD	1.9		732		NS	0.04	269	18

[+] Rainfall for 4 of the 5 rainfed summer sites averaged 725 mm throughout the growing season. That for Poza Rica in the winter was 260 mm. Data are means of 6 locations.
[a] Data are means of two year's data from Tlaltizapan winter cycle.

Rates of gain per cycle in grain yield under severe stress appear to be diminishing. From C_0 to C_2, C_2 to C_4, and C_4 to C_6, the percentage gains per cycle were, respectively, 4.2%, 3.8% and 3.3%. Under conditions of post flowering stress (S_2), the gains per cycle over the same periods were, respectively, 12.0%, 4.0% and −1.9%. Combining data from these two stress levels gives percentage gains in these three periods of, respectively, 8.4%, 4.4% and zero.

Variability for the traits under selection may have been exhausted, and a study of inheritance of drought resistance and components of genetic variance is currently being conducted to examine that possibility. Small, but significant changes in selection methods may also account for diminished gain in recent cycles. We have learned that it is absolutely essential to provide at least 4 metres width of borders between different furrow-irrigation treatments, and that it is important to discard at least 50 cm of row bordering alley ways. The importance of measuring *shelled* grain weights under stress conditions (rather than using a constant, assumed shelling percentage) cannot be overemphasized, since variation in grain number per ear is a major source of variation in yield. Compromises on methodology could account for some of lack of progress in later cycles. Within family improvement for 'good plant type' in a non-stress environment may have reversed some of the gains of selection made under stress.

Finally, caution must be exercised in predicting pure-stand response of a genotype to water stress based on performance in single progeny rows where weakly competing neighbours can give a genotype an atypical advantage.

What changes have occurred in the plant to account for these gains? No measurements have been made that relate to changes occurring in osmotic potential, hormone levels or metabolite accumulation. Trends in selected families towards reduced canopy temperatures, increased rooting intensity, more rapid leaf, stem and silk elongation and delayed leaf death under stress suggest that these plants are finding and extracting more soil water. Increases in capacity to establish larger number of kernels per plant under stress also suggest that considerable gains in general stress tolerance have been made, possibly through selection for synchronization of pollen-shedding and silk emergence (Table 5) (Dow *et al.*, 1984).

Current activities in drought resistance

With the application of methodology developed in the population Tuxpeño on a larger scale, research in drought resistance in tropical maize at CIMMYT has entered a new phase.

Recurrent selection in elite germplasm

Four elite maize populations of good agronomic type and with high yield potential (Table 6) have been selected for recurrent selection for improved performance under drought. Because of resource limitations each population is being tested in alternate winter cycles under estimated drought at Tlaltizapan, so that each cycle of improvement takes 2 years to complete. Each material will be selected in a second environment, which will provide a timing of drought stress different than that experienced at Tlaltizapan. For example, it is hoped to screen 1500 S_1 families of Pool 26, La Posta and Pool 18 near Obregon (latitude 28N, altitude 10 m) in cooperation with INIA staff from the Mexican National Maize Program. This site, situated in the Sonora Desert, exposes April-sown maize to a preflowering environment which is rainfree and which has average daily maximum temperatures of 40C. Lines from this unreplicated nursery will be screened for reduced canopy temperature, and against leaf rolling and leaf firing in a preflowering stress.

When drought is relieved prior to flowering, anthesis and silking characteristics and yield will be measured. 250 superior lines will be selected based on their performance under stress relative to their performance under normal irrigation at the same site. This superior fraction will be grown in replicated yield trials at Tlaltizapan under three water regimes. One of the water regimes (S_3) differs from that previously described in that water is applied 3–4 weeks after 50% silking (as determined under non-stress conditions) when all pollen has been shed, and the families are scored for recovery 10-15 days later. This score generally reflects the quantity and depth of colour of green leaf area present on each plant. In addition, more emphasis is being placed on erect leaves and small tassels. The superior 40% of lines selected at Tlaltizapan will be recombined in Poza Rica the

Table 6 Characteristics of lowland tropical maize populations selected for recurrent improvement in perforamnce under drought.

Population	Maturity[a] (days)	Grain Colour	Grain Texture	Special Disease Resistances	Current yield potential (tons ha^{-1})	Family structure
Pool 26	115	Yellow	Dent	P. sorghi H. maydis	9	S_1
La Posta	120	White	Dent	P. sorghi H. maydis Streak virus	9	S_1
Pool 18	95	Yellow	Dent/ Flint	P. sorghi H. maydis	6	S_1
Pool 16	90	White	Dent	P. sorghi H. maydis Streak virus	6	Full-sib

[a] Days to harvest in an environment averaging 30C and 21C, respectively, for daily maximum and minimum temperature.

following summer, and 1500 new S_1 lines will be formed the following winter in Tlaltizapan.

The fourth material, Pool 16, is undergoing full-sib recurrent selection for yield improvement in Burkina Faso under the direction of SAFGRAD staff based in Ouagadougou. Families are presently being selected on the basis of performance in contrasting water regimes provided by tied or untied ridges. CIMMYT will complement this in alternate years by growing the same families at Tlaltizapan in the normal drought nursery.

To date one cycle of S_1 progeny testing has been completely under drought at Tlaltizapan in La Posta and Pool 26, and 1500 S_1 families of Pool 18 have been sown in Obregon under normal irrigation and under preflowering drought stress. In November 1986 full-sib families from Pool 16 and superior S_1 families from Pool 18 will be sown at Tlaltizapan for the first time.

Formation of a sub-tropical drought-resistant pool

Another activity which has been initiated at CIMMYT is the formation of a sub-tropical drought-resistant pool. This will be a composite of germplasm which has unique drought-tolerant properties, though it may not be high yielding under conditions of non-limiting water supply.

Because gain in yield under water stress in the population Tuxpeño Drought has slowed in recent cycles, cycle 8 of this material has been removed from the recurrent selection program and is being used as the basis of the drought resistant pool. When sources of drought resistance are identified by national programs and other researchers, these will be evaluated under simulated drought conditions at Tlaltizapan. If found to possess drought resistance, these will be crossed with Tuxpeño Drought, or incorporated directly into the pool.

One source of unique drought tolerance is reputed to be the landrace Michoacan 21, the original source of the "latente" gene. Lines and hybrids derived from this material have the capacity to defer developmental events (such as flowering), to recover rapidly after stress, to transpire more under irrigation, to transpire less under stress, and to maintain flowering synchrony over a range of drought conditions (Castleberry and Lerette, 1979; Castleberry, 1983). Some latente lines maintain physiological function at lower leaf water potentials than normal maize germplasm (Long, 1974), and have high abscisic acid levels in the leaves (Larque-Saavedra and Wain, 1974; Ackerson, 1983). The agronomic type of Michoacan 21, a landrace adapted to 1800 m altitude and 20N latitude, is poor: yields under good conditions are low, root lodging is extensive and it is very susceptible to ear rots. Nonetheless, it has been used with success in combination with U.S. cornbelt germplasm (Castleberry and Lerette, 1979; Castleberry, 1983). Full-sib families of Michoacan 21 and its cross with cornbelt germplasm have been screened for drought resistance at Tlaltizapan, and a small superior fraction of these families will be crossed to Tuxpeño Drought during 1986. Other sources of drought tolerance may come from germplasm which has the capacity to germinate from considerable depths in the soil, such as Hopi maize types.

When crosses between Tuxpeño Drought and 'Latente' families have been composited, it is likely that the pool will be improved by a half sib-S_1 breeding method, in which selfs are made in half-sib families under moderate drought stress. The S_1 families will then be recombined in a half-sib block under non-stress conditions. Introductions to the pool would normally be made by selfing plants within inroduced lines under moderate drought stress.

It is hoped that within five years a subtropical pool of mixed grain colour and texture and with a high level of drought resistance will be available as a source material to national maize programs throughout the world.

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16 Comportement et selection de certains genotypes de maïs dans les conditions naturelles de secheresse

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Resume La recherche menée à Kamboinsé depuis 1979 sous l'égide de IITA-SAFGRAD a fait ressortir une nette réponse de rendement du maïs aux billons cloisonnés sur des sols ferrugineux tropicaux communs dans la Savane Soudanienne.

En cultivant une gamme de variétés sur billons simples et cloisonnés, la performance de ces variétés dans deux conditions de stress de sécheresse (élevé et moindre) peut être evaluée. A partir de ces observations une nouvelle méthode de test de génotypes de maïs sous deux niveaux de stress dans les conditions habituelles de culture a été proposée.

Deux variétés; Safita 104 et Temperate x Tropical 42 se sont révélées prometteuses pour la résistance à la sècheresse et deux autres variétés, Local Kamboinsé et Composite 77 BD se sont montrées "susceptibles" à la sécheresse.

Introduction

Le sorgho est reconnu plus résistant à la sécheresse que le maïs (Hsiao et al, 1976). Cette supériorité a été rapportée avec beaucoup de détails par Fischer et al. (1983). C'est pour cette qualité que le sorgho a été pendant longtemps et reste encore la principale céréale cultivée dans la savane Nord Guinéenne et Soudanienne de l'Afrique de l'Ouest. Cependant, ces dernières années le maïs est en train de prendre le pas sur le sorgho dans la Savane Nord Guinéenne pour les raisons suivantes selon Kassam et al (1975).

1. Les rendements moyens expérimentaux de maïs dans la savane sont de façon consistante 2 à 3 fois supérieurs aux rendements moyens des variétés locales améliorées de sorgho.
2. Le maïs est résistant aux attaques des oiseaux.
3. Les épis de maïs protégés par les spathes résistent mieux aux insectes et aux intempéries durant la maturation.
4. Le potentiel de rendement théorique des variétés précoces de sorgho non photosensibles est juste aussi élevé que celui du maïs. Par contre la qualité inférieure du grain avec la susceptibilité à la moisissure et les difficultés qu'engendre la récolte sous des conditions humides rendent ce sorgho inacceptable comme alternative céréale en Afrique de l'Ouest. Les variétés tardives photosensibles ne paraissent pas avoir le même potentiel de rendement que le maïs.

Cependant, la plupart des zones maïsicoles dans le monde sont sujettes à la sécheresse qui est l'un des facteurs limitants de la stabilité de rendement, particulièrement dans les zones semi-arides. Denmead et Shaw (1960) signalent que la sécheresse peut réduire le rendement de maïs de 25%, 50%

et 21% selon qu'elle survienne juste avant, pendant ou après l'apparition de la soie.

Pour Shaw (1983) une sécheresse précoce survenant au cours de la période végétative du maïs n'a pas d'effet négatif sur le rendement sauf si la sécheresse est trop sévère, conduisant à la mort des plantes et à une baisse de la densité de population. Ce même auteur indique qu'une sécheresse modérée durant la période végétative peut entraîner le développement d'un système racinaire dense et profond, conduisant à une augmentation de rendement.

L'avenir du maïs dans les zones semi-arides dépendra en grande partie de l'efficacité des méthodes à utiliser pour réduire le risque de Stress de sécheresse. Si les facilités d'irrigation ne sont pas disponibles, les seules solutions possibles devraient être recherchées à travers les pratiques culturales qui augmentent ou préservent l'humidité disponible dans le sol, permettent aux plantes d'échapper à la sécheresse ou le développement des variétés résistantes à la sécheresse.

La question de savoir si un progrès peut être obtenu dans un programme de sélection pour la résistance à la sécheresse dépend:

1. de l'existence des différences pour le caractère dans les germoplasmes de maïs disponibles;
2. de la variabilité du caractère à l'intérieur d'un même germoplasme;
3. de l'héritabilité de ce caractère;
4. de l'existence d'une méthodologie et des techniques permettant de détecter le caractère et d'identifier les vrais génotypes possédant ce caractère.

Dans cet article, nous comparons différents matériels de maïs sous deux niveaux de stress de sécheresse utilisant une nouvelle méthode et tâchons de mesurer le progrès obtenu après un cycle de sélection plein-frère dans le Pool 16 (matériel tropical développé par le CIMMYT).

Définition de la sécheresse et de la résistance à la sécheresse

D'après Jones (1983), il y a plusieurs possibilités de définir la sécheresse. En termes météorologiques, elle se définit comme longueur de la période non pluvieuse. Le deuxième aspect peut être vu sous la faiblesse de la capacité de retention de l'eau du sol, le troisiè-me sous l'angle d'une évapotranspiration trop élevée. Dans notre cas nous voyons la sécheresse comme une combinaison de tous les facteurs tendant à limiter l'humidité nécessaire à la vie normale des plantes et entraînant une réduction de rendement.

Parmi les différentes compréhensions de la résistance à la sécheresse, nous partageons celle de Levitt (1972), cité par Quizenberry et al (1983). Selon cet auteur, en agriculture, la résistance à la sécheresse est relative à la capacité des plantes cultivées de produire leurs rendements économiques dans les conditions d'humidité limitée. Dans ce contexte qui nous intéresse trois situations sont à distinguer.

Echapper à la sécheresse. C'est le cas des génotypes qui arrivent à compléter leurs cycles durant les périodes pendant lesquelles l'eau est encore disponible. Dans cette situation, développer des variétés dont le cycle est approprié à la longueur de la saison et aménager les dates de semis, peut réduire les risques de sécheresse. Mais si la pluviométrie est bonne, l'on trouve une correlation négative entre la précocité et le rendement du maïs. Dans tous les cas, ces variétes qui échappent à la sécheresse ne sont pas obligatoirement résistantes.

Self protection. ("avoidance") C'est la capacité de la plante de maintenir un taux élevé d'humidité (turgescence) malgré la limitation d'eau dans la couche supérieure du sol soit par le developpement d'un système racinaire profond ou d'un méchanisme de régulation de perte d'eau (Reduction de la surface foliaire, fermeture des stomates) (Hall 1981), soit par la capacité de developper un système racinaire très ramifié.

La reduction des pertes en eau chez le niébé, due à ce mécanisme, a été signalée par Hall (1981). Castleberry et Levitt (1979) rapportent, citant Munoz (1975), que la lignée de maïs 1-104 dérivée de Michuacan 21 et décrite comme latente a les propriétés de retarder son développement sous les conditions de sécheresse et de recouvrer remarquablement après apport d'eau. Elle est résistante à la fanaison et dessication des tissues, transpire plus, sous irrigation et moins sous conditions de sécheresse que le maïs normal. Ceci, disent-ils, est dû aux caractéristiques des stomates.

Pour Levitt (1972), cité par Quizenberry, (1982), la plupart des traits de résistance entrent dans la catégorie de self protection et ils tendent à aider les plantes à se proteger contre la dessication; ils sont de nature xerophytiques donc développés au cours de l'évolution des plantes dans les conditions de sécheresse. Selon Hall (1981) la grande capacité des plantes de développer les mécanismes de self-protection ne conduit pas inéluctablement à une adaptation à la sécheresse.

Tolérance à la sécheresse C'est la capacité de la plante de maintenir ses différentes fonctions sous conditions d'un taux faible d'humidité des tissus.

La maintenance de la turgescence des cellules par adaptation osmotique et la présence de certaines substances chimiques (proline, acide abscisique) sont en partie responsables du mécanisme de tolérance. Dans ce sens Larque-Saavedra et Wain (1974, 1976), cités par Castleberry (1979), ont trouvé que le matériel latente contient une quantité relativement élevée d'acide abscisique dans les tissus.

Cependant, les relations entre les différents mécanismes et le rendement ne sont pas encore claires Quizenberry, (1982).

L'objectif de notre programme, c'est de développer des variétés de maïs qui, sous conditions de sécheresse peuvent donner un rendement économique mais aussi maintiennent un haut niveau de rendement dans des bonnes conditions d'humidité. Autrement dit, la sécheresse se définit comme limitation de l'humidité dans le milieu de culture et résistance à la sécheresse s'entend comme capacité d'un génotype d'être plus productif qu'un autre dans des conditions définies de sécheresse.

Ainsi, la connaissance des composantes de l'environnement dans lequel les plantes sont cultivées est de la plus grande importance avant l'élaboration d'un programme de sélection.

La Savane Soudanienne du Burkina Faso où nous travaillons est caractériseé par 3 à 4 mois de pluie pour un total de 600 à 900 mm. L'évapotranspiration durant cette période (Juin – Septembre) est d'environ 6 mm par jour. Une alternance imprévisible de pluie et de sécheresse est fréquente. Il est rare que l'humidité du sol soit toujours suffisante pour la vie normale des plantes. Pour obtenir une bonne densité des plantes, le semis est généralement effectué après une grande pluie appelée pluie utile. Les génotypes à développer pour un tel milieu devraient être capables de tirer le maximum d'avantage des rares pluies périodiques, donc posséder des taux photosynthétiques élevés, des réponses stomatales sensibles à la sécheresse, un système racinaire dense mais pas nécessairement profond et une grande capacité d'ajustements osmotiques. Aussi la capacité des génotypes de surmonter des périodes de basse turgescence des cellules et de recouvrer rapidement après une pluie serait d'une grande importance.

Le génotype possédant ces différents traits associés à un rendement économique et stable dans les conditions de sécheresse mais aussi capable d'exhiber des rendements élevés dans des conditions optimales d'humidité se rapproche de l'idéal.

Sélection pour la résistance à la sécheresse

Del Rosario et al (1984) distinguent deaux méthodes: (empirique et physiologique).

Méthode empirique

Le concept de cette méthode s'articule sur le rendement qui est l'expression finale de tous les caractères relatifs à la productivité sous conditions optimales et de stress de sécheresse. Donc on mesure le rendement comme critère de sélection. Cette méthode procède de plusieurs approches.

Blum (1979) cité par Fischer et al (1983) en a décrit deux:

- La première accepte que les génotypes à hauts potentiels de rendements sous conditions optimales peuvent maintenir ces potentialités sous conditions de sécheresse. Donc, sélectionner pour des hauts rendements stables dans plusieurs environnements conduirait indirectement à améliorer lesdits génotypes pour la résistance à la sécheresse. Sous ce même concept une alternative serait de sélectionner pour la résistance à la sécheresse parmi les génotypes à hauts rendements stables. Cette méthode implique des essais multilocaux dans différentes environnements et revient donc assez chère. Aussi, Fischer (1983) analysant des données de Russel (1974) démontre que les différences de rendement de certains hybrides de maïs sous conditions de sécheresse étaient dues à d'autres facteurs indépendants de la potentialité de rendement en tant que telle. Chez le blé la résistance à la sécheresse est indépendante du potentiel de rendement (Blum 1983). Donc dans un programme de sélection il serait préférable de manipuler le rendement (le maintenir ou l'améliorer) et aussi certains traits spécifiques responsables de la résistance à la sécheresse.
- La deuxième philosophie; Toujours selon Fischer et al (1983) s'accordant avec Blum (1979), les génotypes devraient être sélectionnés et testés dans les conditions de sécheresse. Aussi, d'autres chercheurs comparent le rendement sous stress de sécheresse et conditions optimales définissant aussi la résistance à la sécheresse en fonction du pourcentage de réduction de rendement sous le stress de sécheresse par rapport au non stress de sécheresse. Signalons que sous cet aspect plusieurs chercheurs ayant travaillé sur la résistance à la sécheresse ont utilisé soit des environnements à faible pluviométrie, soit des environnements secs avec irrigation soit les deux à la fois.

Arboleda et compton (1974) rapportés par Fischer et al (1983) ont effectué des études de sélection massale sur le maïs en Colombie en saison pluvieuse (600 mm) et sèche (300 mm) séparément et en combinaison. Trois cycles de sélection en saison pluvieuse permirent d'augmenter le rendement de 10,5% pour cette saison et seulement de 0,8% pour la saison sèche.

Rosenow et al (1983) ont débuté une sélection sur le sorgho dans les conditions naturelles des régions arides à faible pluviométrie. Les génotypes identifiés ont été testés sous irrigation pour leur permettre d'exprimer leur plein rendement. Aussi, le même auteur a testé plusieurs germoplasmes de sorgho dans différents environnements de sécheresse à des différentes dates de semis et différents régimes d'eau Cette méthode a permis de provoquer la sécheresse à différents stades du développement des différents germoplasmes de sorgho. Ainsi, ils ont pu identifier deux types de réponse à la sécheresse chez le sorgho. Un type s'est exprimé avant la floraison et le second durant le remplissage des graines. Aucun génotype en comparaison ne possédait les deux à la fois.

Au CIMMYT Fischer et al (1983) ont utilisé l'irrigation controlée pour évaluer 8 géntoypes de maïs et améliorer la population tuxpeno pour la résistance à la sécheresse. La sécheresse a été imposée à différents stades du développement des plantes (irrigation juste pour la levée, irrigation jusau'au stade de l'initiation florale et ensuite sécheresse irrigation normale jusqu'à la récoilte). Trois cycles de sélection recurrente ont été accomplis dans la population tuxpeno utilisant un index calculé sur le base du rendement sous stress et non stress de sécheresse, la dynamique d'élongation des feuilles, la synchronisation entre l'anthèse et la sortie des soies, la température des feuilles et la surface foliaire perdue au cours du remplissage des graines. Neuf et demi (9,5%) de progès ont été enregistrés pour le rendement sous stress de sécheresse.

L'amélioration pour la résistance à la sécheresse par sélection pour le rendement sous stress de sécheresse est possible mais doit être de longue durée et pose certaines difficultés. L'une de ces difficultés est la faible héritabilité du rendement et de ses composantes qui se trouvent très affectés sous conditions de sécheresse. Aussi des variétés sélectionnées sous stress de sécheresse peuvent donner des rendements bas dans les conditions optimales (Blum, 1983).

Méthode physiologique

Cette méthode consiste à sélectionner à partir des caractères physiologiques ou/et morphologiques spécifiques qui pourraient procurer à la plante la capacité de se protéger ou de tolérer la sécheresse (maintenance d'un grand potentiel d'eau dans les feuilles, augmentation de la résistance stomale, rapide élongation des cellules, accumulation de proline et acide abscisique etc....).

Cette méthode procède de plusieurs approches, approches décrites dans plusieurs sources de littérature Ekanayake et al, 1985; Wright et al 1983; Walker et al, 1983; Jones, 1983. Quizzenberry, 1982; Blum, 1983; Rosenow et al, 1983; Banda et al, 1983; Del Rosario et al 1984; Sinclair et al 1975).

Cette approche physiologique a été géneralement appliquée aux lignées pures de maïs (Maschingaidze 1984). Cette méthode physiologique demande souvent des appareillages sophistiqués et des laboratoires sans compter qu'il n'est pas réaliste de toujours s'attendre á une correlation élevée entre chacun des caractères physiologiques ou morphologiques et le rendement sous condition de sécheresse (Garrity, 1982, Del Rosario, 1984). Del Rosario et al 1984 estiment que parmi les deux méthodes principales de sélection (Empirique et physiologique) l'approche empirique a plus de chance de succès. Il semble donc que sélectionner en tenant compte du rendement et de certains traits morphologiques facilement observables et mesurables au champ serait l'une des meilleures approches pour la sélection pour la résistance à la sécheresse.

Materiels et methode

Matériels

En 1984, 20 matériels de différentes origines (CIMMYT, IITA-SAFGRAD, IITA-Ibadan, Burkina Faso, Sénégal et Tanzanie, précoces et intermédiaires, améliorés et locaux ont été testés dans l'essai KT 38.

En 1985, le même essai a été répété comportant les mêmes variétés. Trois autres essais, EVT-ESR comportant 16 variétés précoces résistantes à la striure originaires du CIMMYT et de l'IITA-Ibadan, EVT-10E composé de 15 variétés précoces du CIMMYT et de l'IITA-Ibadan et RUVT-1 composé de 12 variétés précoces originaires de l'IITA-SAFGRAD, Sénégal et CIMMYT ont été conduits.

Pour l'évaluation du progrès génétique pour la résistance à la sécheresse accompli dans le Pool 16 après un cycle de sélection, un essai composé de 10 entrées dont le cycle 1 et le cycle 0 de sélection, EV 84 Pool 16 DR (résistante), EV 84 Pool 16 DS (variété susceptible), Latente x Latente, XL 73, Tuxpeno DR C6, Safita 104 x German Imbred Line (resistante à la sécheresse), Michuacan 21 et JFS (Jaune Flint de Saria, local témoin) a été implanté.

Méthode

La recherche menée depuis 1979 a fait ressortir une nette réponse de rendement du maïs aux billons cloisonnés sur les sols ferrugineux tropicaux communs dans la Savane Soudanienne (Rodriguez, 1985; IITA/SAFGRAD, 1986). Selon le système Américain de classification de sols (soil Taxonomy), les sols ont été identifiés principalement comme Palenstalfs, Plinthustalfs et Haplustalfs (Smaling, 1985). En cultivant une gamme de variétés sur billons simples et billons cloisonnés, la performance de ces variétés dans deux conditions de stress de sécheresse (élevé et faible) peut être évaluée.

Les essais ont été conduits à Kamboinsé (Burkina Faso) sur sols ferrugineux tropicaux très lessivés. Kamboinsé est situé à 12°28′ N à 14 km au Nord de Ouagadougou avec une moyenne pluviomérique annuelle de 800 mm, altitude 300 m. Un modèle split-plot a été utilisé. Les parcelles principales étaient représentées par les systèmes de billonnage (billons simples et billons cloisonnés), les sous-parcelles par les différentes entrées. Pour l'essai KT 38 une densité de 44000 plants/ha dans des parcelles de 3 lignes de 5 m long répétée 6 fois avait été adoptée avec la dose de 97-46-30 kg/ha de N-P_2O_5-K_2O en 1984, réduite à 74-46-30 en 1985.

Pour les autres essais, une densité de plantes de 53000 plants/ha avait été adoptée, avec des parcelles de 4 lignes de 5 m de long et avec 4 répétitions.

Résultats et Discussion

En 1985, à Kamboinsé où les essais ont été conduits, la pluviométrie a été relativement bien répartie avec un total de 573.5 mm. Dans tous les essais, la densité de population souhaitée a été effectivement obtenue. Dans aucun essai une différence statistiquement significative n'a été observée pour les plantes récoltées. Ainsi, les différences de rendement obtenues ne sont pas dues au fait des différences de nombre de pieds à l'hectare.

Les moyennes des carrés des erreurs expérimentales (variances pour les rendements) ont été d'abord calculées séparément pour chaque niveau de stress et ensuite accociées après que les F tests aient montré qu'il n'y a pas de différence entre les variances.

EVT-ESR

15 variétés précoces résistantes à la striure et un témoin local ont été testés dans cet essai.

Le Tableau N° 1 présente la moyenne des rendements, ses composantes et jours à 50% de formation de soie. La Fig. 1 illustre le rendement, il a été enregistré une réponse statistiquement significative (niveau 5%) aux billons cloisonnés (1842 contre 3889). Il existait aussi des différences hautement significatives entre les variétés. L'interaction système de billonnage x variété n'était pas significative. Parmi les deux variétés les plus précoces, Jaune Flint de Saria (V15) et Kaïchan Jaune (V16), il n'y a pas eu de différence significative pour le rendement. Dans le second groupe de maturité, EV 8430-SR BC3 (V5) et Pool 16 SR BC4 (V12) ont donné des rendements statistiquement plus élevés que ceux de Pool 16 C4-81 (V11) et DMR-ESR-Y (V10).

Une interaction significative niveau de stress x variétés a été observée pour le poids de 1000 graines. EV 8430-SR BC3 (V5) a donné un poids de 1000 graines statistiquement plus élevé que EV 8435 SR BC4 (V7) et EV 8449 SR BC3 (V8) au niveau élevé de stress de sécheresse. Au niveau moindre de stress, c'est Pool 16 SR BC4 qui a donné le poids le plus élevé de 1000 graines. Le poids de 1000 graines a été significativement réduit par la sécheresse pour toutes les variétés.

EVT-10E

14 matériels précoces (Pools et Populations) et un témoin local (JFS) ont été testés dans cet essai. Le rendement moyen, ses composantes et le nombre de jours à 50% de la floraison femelle sont consignés dans le Tableau n° 2 et la Fig. 2 montre les rendements des variétés testées sous les deux niveaux de stress de sécheresse. Pour le rendement, une réponse hautement significative aux billons cloisonnés a été observée (2299 kg/ha sur billons simples contre 4328 kg/ha sur billons cloisonnés). Les différences entre variétés pour le rendement ainsi que pour ses composantes ont été également significatives. L'interaction variétés x niveau de stress de sécheresse n'a été significative (seuil 5%) que pour le nombre d'épis par plant mais ceci ne s'est pas reflété sur le nombre de graines par m2. Les deux variétés les plus précoces, Pool 17 (C14) (V3) et Jaune Flint de Saria (V15) ont donné des rendement statistiquement similaires. Pop 31 (C1) (V6), Pop 49 (C1) (V7), TZESR-Y (C2) (V13) et Pool 16 (IITA) (V14) ont statistiquement surclassé Poole 15 (C14) (V1). Pour le nombre d'épis par plant, Pop 49 (C1) (V7) a donné un nombre statistiquement plus élevé d'épis par plant par rapport á Pool 16 (C14) (V2) et Pool 18 (C14) (V4) au niveau de stress élevé de sécheresse. Au niveau de stress moindre de sécheresse Pool 18 (C14) (V4), Pop 30 (C2) (V5) et TRZESR-Y (C2) (V13) ont donné les nombres d'épis par plant les plus élevés.

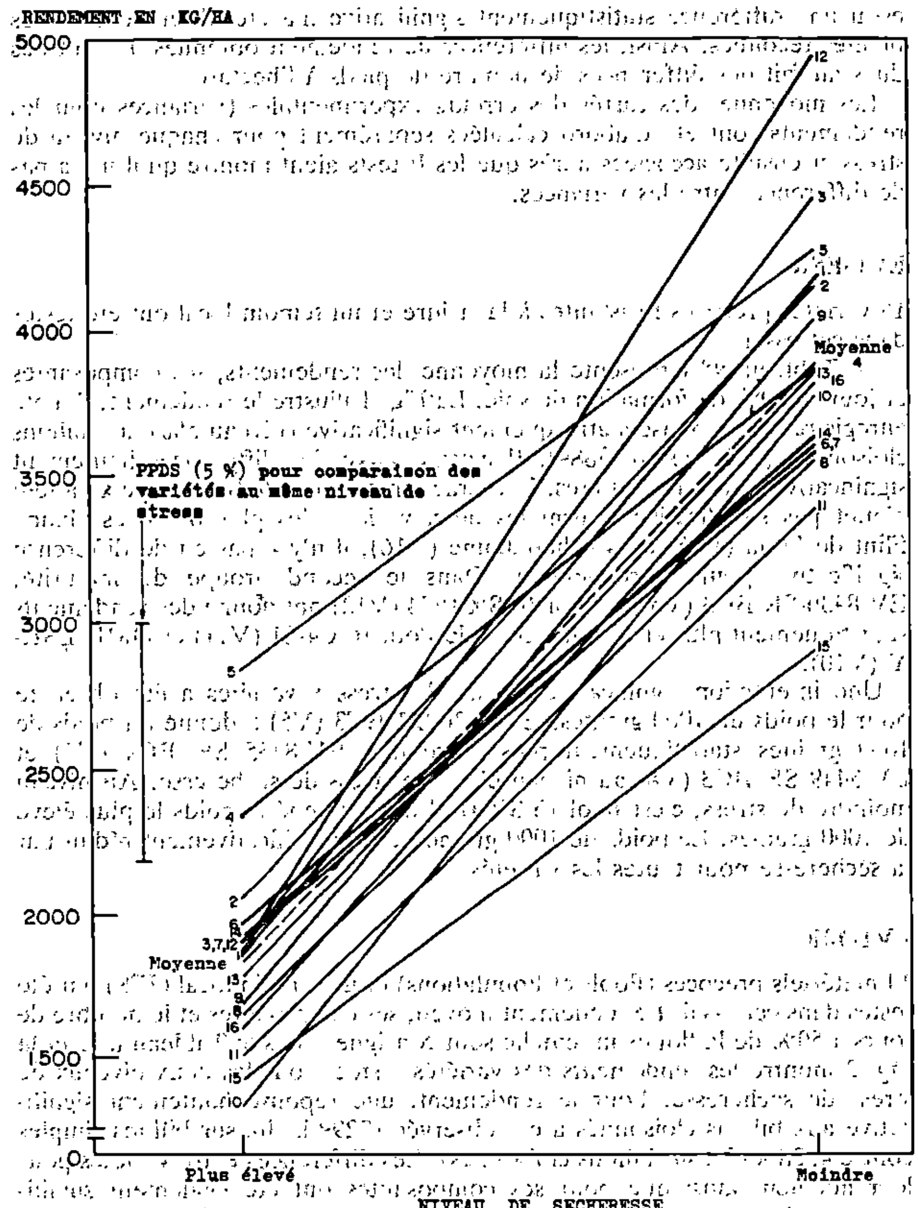

Figure 1 · Rendement en grains de 16 variétés de maïs testées dans l'essai EVT-ESR sous deux niveaux de sécheresse.

RUVT-1

11 variétés précoces de diverses origines avec un témoin local ont été testés dans cet essai.

Pour le rendement et ses composantes, des différences significatives entre les variétés et les systèmes de billonnage sont observées. Une interaction V x Niveau de stress significative pour le rendement, le pourcentage d'égrainage, le poids de 1000 graines et le nombre de grains par m2 a été

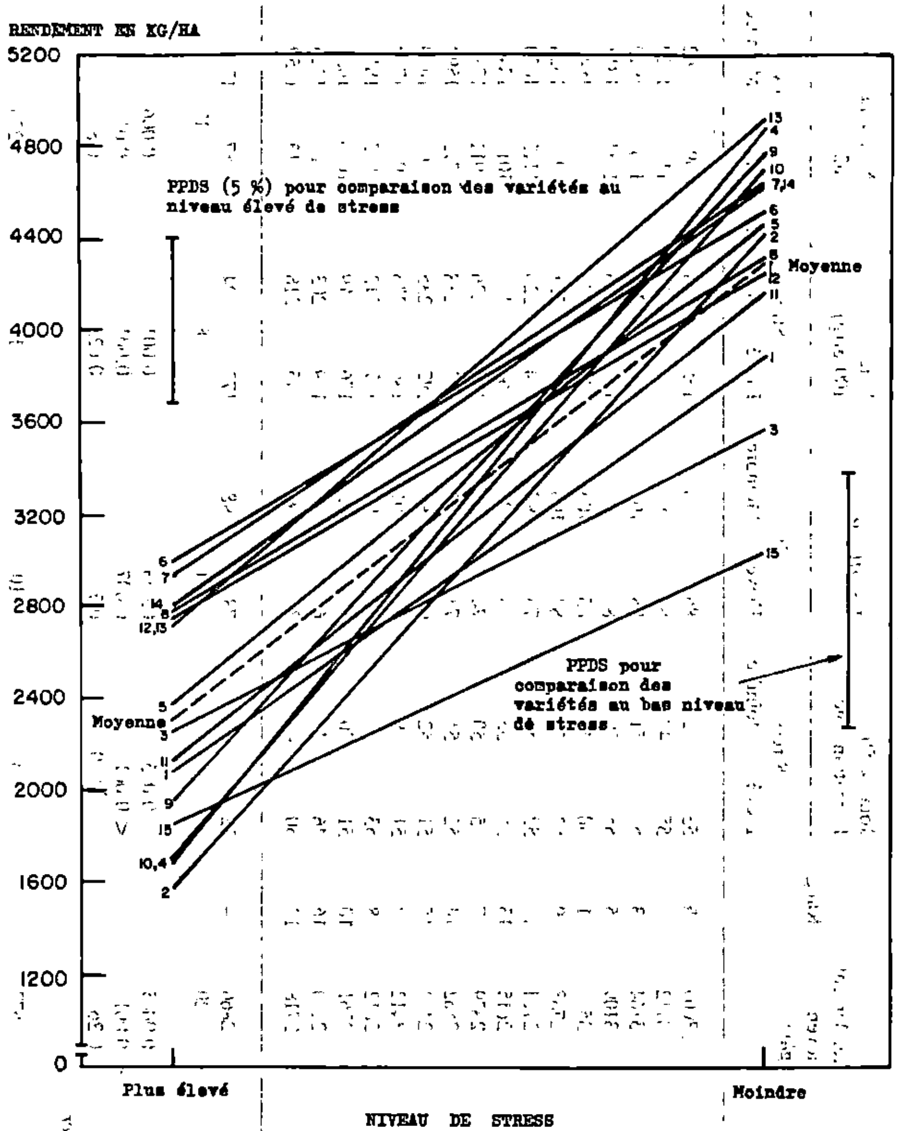

Figure 2 Rendement en grain de 5 variétés testées dans EVT-10 E sous deux niveaux de stress de sécheresse, Kamboinsé, Burkina Faso, 1985.

aussi obtenue (Tableau 3). Ici, il faut distinguer 3 groupes selon la maturité: 40-43, 44-47 et 48-51 jours à 50% de soie.

Table 1 Rendement en grain (humidité 15%), ses composantes et jours à 50% de formation de soies des variétés testées dans EVT ESR sous deux niveaux de stress de sécherésse, Kamboinsé, (Burkina Faso), 1985.

N°	Noms des variétés	Rendement moyen kg/ha	Rang	Jours à 50% formation soies		Epis/100 Plts		Poids/ 100 gr(g)		N° graines/ m2	
				Stress		Stress		Stress		Stress	
				Elevé	Moindre	Elevé	Moindre	Elevé	Moindre	Elevé	Moindre
1.	TZESR-W. M.G. 82	3009	6	53	52	86	98	165	224	1097	1862
2.	TZESR-W. Ilonga 82	3112	4	55	49	83	96	170	216	1199	1929
3.	TXESR-W. ACR 82	3164	3	53	51	88	104	166	233	1106	1919
4.	TZESR-WIL-(A)-84	3109	5	55	50	89	99	186	213	1251	1817
5.	EV 8430-SR BC3	3561	1	50	49	85	103	191	230	1484	1847
6.	EV 8431-SR BC3	2788	9	52	52	82	100	188	221	1039	1628
7.	EV 8435 SR BC4	2724	11	52	52	78	97	164	220	1115	1630
8.	EV 8449 SR BC3	2615	13	55	53	78	95	164	196	1015	1840
9.	DMR-ESR-W	2879	7	55	50	74	100	182	226	911	1783
10.	DMR-ESR-Y	2562	14	52	51	73	97	172	238	772	1590
11.	Pool 16 C4-81	2452	15	51	52	68	94	182	235	808	1440
12.	Pool 16 SR-BC4	3412	2	51	48	77	101	189	276	985	1790
13.	TZESR-Y Kamboinsé 82	2812	8	53	52	70	99	167	212	1073	1816
14.	TZESR-ACR-82	2761	10	51	50	80	103	176	219	1060	1654
15.	Jaune Flint de Saria	2170	16	46	45	64	89	159	203	883	1426
16.	Kaïchan jaune	2718	12	50	44	76	91	145	218	1113	1750
	Moyenne	2866	—	52	50	78	98	173	224	1057	1732
	C.V. %	20		6		11		8		17	
	Prob. de F										
	Systéme de billonnage	0.0045		0.005		0.003		0.001		0.006	
	Variétés	< 0.001		< 0.001		0.007		< 0.001		< 0.01	
	S x V	0.26		0.60		0.7		0.023		0.8	
	PPDS (5%) pour comparer les variétés:										
	Moyennes	577		3		10		16		236	
	Au même système de billonnage	816		4		14		23		334	

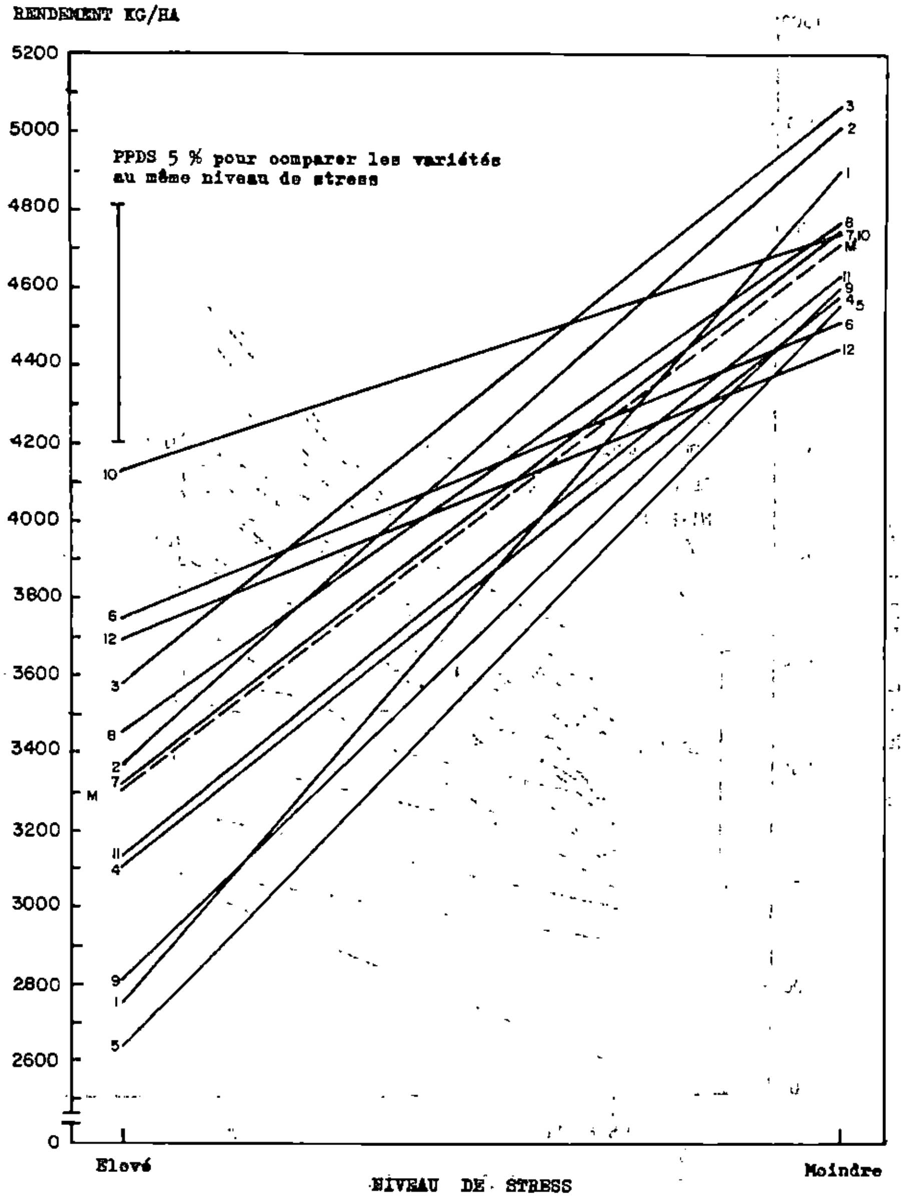

Figure 3. Rendement de 12 variétés testées sous 2 niveaux de stress de sécheresse, Kamboinsé, Kurkina Faso, 1985

Dans le premier groupe Safita 104 (V10) a donné un rendement significativement (au seuil 5%) plus élevé que Compuesto Selection Précoce (V8), sous conditions de sécheresse relativement élevée, mais pas de différence sous conditions de sécheresse moindre (Fig. 3). Dans le deuxième groupe, il n'y a pas de différence de rendement entre les variétés (V2 at V3) pour les deux niveaux de sécheresse.

Pour le troisième groupe, SIDS 8245 (V6) et Capinopolis 8245 (V7) ont donné un rendement significativement plus élevé que Synthetic C (V1) et

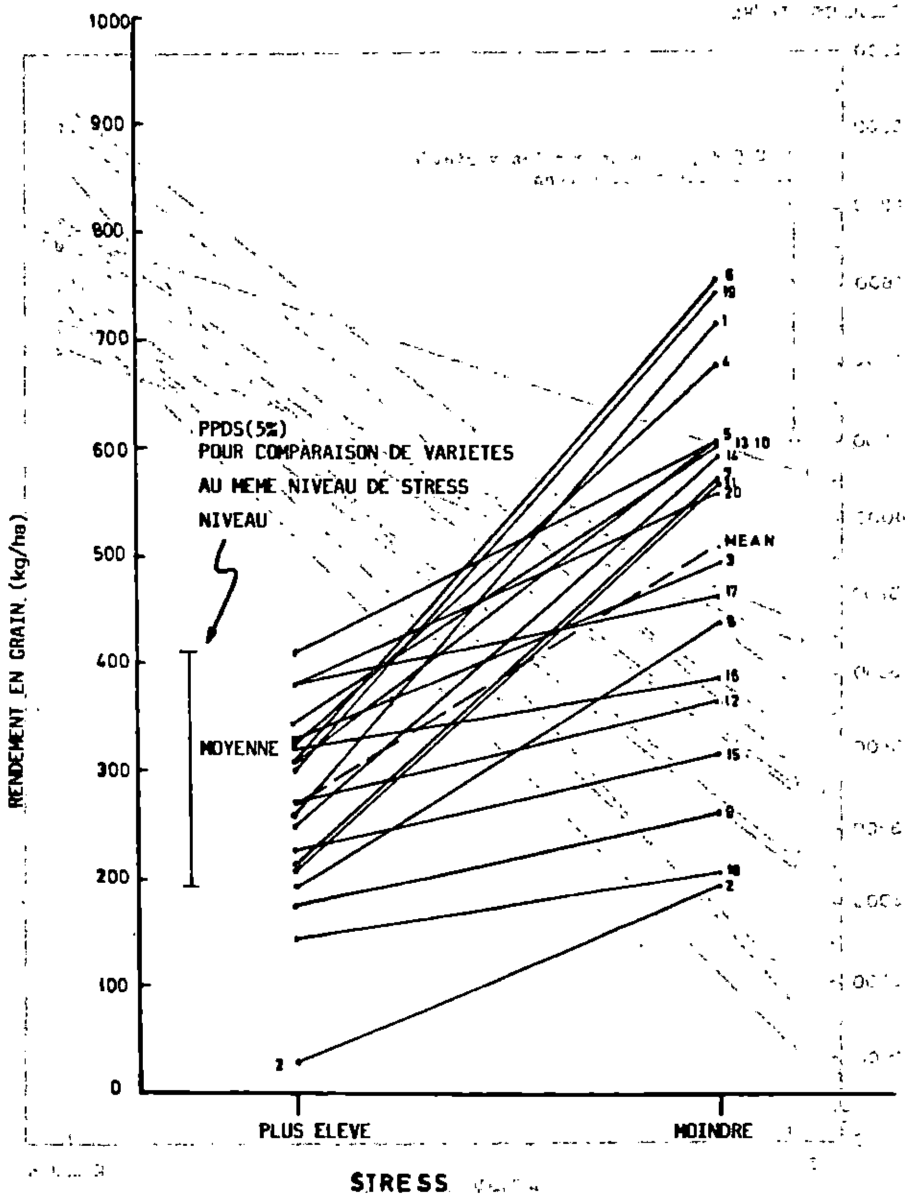

Figure 4, Rendement en grain de 20 variétés a 2 niveaux de stress de la sécheresse. Kamboinse (Burkina Faso) 1984.

XL 73 (V5) sous conditions de stress élevé, tout en en maintenant des rendements parmi les meilleurs au niveau de stress réduit (Fig. 3). Toujours dans ce groupe, Synthetic C parait être susceptible à la sécheresse (2746 kg/ha sous stress élevé contre 4901 kg/ha sous conditions de moindre sécheresse).

La variété "susceptible" Synthetic C a montré une réduction de nombre de graines/m2 de 29% contre 11% pour la variété dite "résistante" Capinopolis 8245 dont le rendement a été réduit par la sécheresse de 30% contre 44% pour Synthetic C.

KT 38

Cet essai comportant 20 variétès précoces, intermédiaries locales et améliorées d'origines diverses a été conduit en 1984 et 1985. En 1984 la pluviométrie a été très faible (227.4 mm), trois petites irrigations de 8 mm chacune étaient indispensables afin d'assurer une petite récolte en grain. Malgré tout, le rendement était très bas même sur les billons cloisonnés. Une différence significative (Niveau 5%) pour rendement a été observée entre les systèmes de billonnage (269 kg/ha sur billons simples contre 509 kg/ha sur billons cloisonnés). Une différence hautement significative obtenue entre les variétés est une indication possible de la réponse différentielle des variétés à la sécheresse. L'interaction (système de billonnage x variétés) a été significative à 7% avec une erreur expérimentale très élevée (49,2%). Le Tableau n° 4 montre la moyenne des rendements, jours à 50% de formation de soie et la hauteur des plantes des 20 variétés testées dans cet essai. Les données de la floraison sont celles observées sur les billons cloisonnés, seules valables pour donner une indication de la maturité des variétés testées. La performance relative des variétés sous les deux niveaux de conditions de sécheresse est indiquée sur la Fig. 4. Les 5 meilleures variétés sur le plan rendement étaient: local Loumbila (534 kg/ha), Pool 18 (SAFGRAD), Temperate x Tropical 42, Local Raytiri et Local Koudougou. Bien que les variétés locales (Raytiri, Loumbila, Koudougou) étaient parmi les plus précoces de l'essai, ce ne sont pas toutes les variétés précoces qui ont montré une bonne performance. Aucune relation entre la précocité (jours à 50% de la formation des soies) et le rendement en grain sous conditions de stress de sécheresse élevé n'a été observée.

En 1985, le mois de Juillet a été très pluvieux entraînant une stagnation prolongée de l'eau dans les parcelles à billons cloisonnés. Des différences significatives entre variétés et interaction variétés x niveau de stress de sécheresse ont été observées pour le rendement, le nombre d'épis/100 plantes, le poids de 1000 graines et le nombre de grains/m2 (Tableau n° 5).

Etant donné qu'un resemis avait été effectués pour cause de mauvaise germination et que l'eau avait stagné dans les parcelles aux billons cloisonnés, les données relatives aux jours à 50% de formation de soie ne sont pas des indicateurs fiables pour la maturité des variétés testées dans cet essai.

Les données sur la floraison de ces variétés disponibles dans nos différents rapports annuels permettent de classifier les 20 matériels testés en quatre groupes de maturité (1) 42-45 jours à la formation de soie, 46-49 jours, 50-53 jours et 54-57 jours. Dans le premier groupe Safita 104 (V10) a donné un rendement significativement plus élevé que celui de Jaune Flint de Saria, (V7) mais comparable à celui de Local Loumbila (V6) sous conditions de stress de sécheresse élevée. Dans les conditions de stress de sécherese moindre, Local Loumbila (V6) et Safita 104 (V10) ont suprassé significativement Local Pabré (V5).

Toutes les trois variétés (Pool 34 QPM (V8) TZE4 (V11), TZE 16 Across W (V17) classées dans le second groupe ont un rendement similaire aux deux niveaux de stress de sécheresse.

6 variétés du 3e groupe (Local Diapaga (V3) early yellow (V9) Safita 2 (V12), Temperate x Tropical N° 42 (V13), Pirsaback (1) 7930 (V16) et Pool 18 (SAFGRAD) (V19) ont donné un rendement similaire au niveau élevé de stress de sécheresse (Fig. 5). Temperate x Tropical 42 (V13) a significativement surclassé Local Kamboinsé (V2). Au niveau moindre de

Table 2 Rendement en grain (humidité 15%), ses composantes et jours à 50% de formation de soies des variétés testées dans EVT-10E sous deux niveaux de stress de sécheresse, Kamboinsé, (Burkina Faso), 1985.

N°	Noms des variétés	Rendement moyen kg/ha	Rang	Jours à 50% soie		N° Epis 100 plantes		Poids 1000 graines (g)		N° graines/ m2	
				Stress		Stress		Stress		Stress	
				Elevé	Moindre	Elevé	Moindre	Elevé	Moindre	Elevé	Moindre
1.	Pool 15 (C14)	2977	13	53	50	86	91	182	226	1129	1701
2.	Pool 16 (C14)	3000	12	54	50	58	92	192	261	782	1701
3.	Pool 17 (C14)	2917	14	48	47	79	94	188	241	1164	1478
4.	Pool 18 (C14)	3253	9	54	51	60	100	198	260	835	1863
5.	Pop 30 (C2)	3417	7	52	52	86	100	196	212	1206	2105
6.	Pop 31 (C1)	3750	2	49	49	88	99	197	231	1466	1959
7.	Pop 49 (C1)	3790	1	52	53	100	96	182	215	1594	2176
8.	Pop 61 QPM (C1)	3560	5	51	50	93	98	188	226	1475	1916
9.	BUESR-W (C1)	3377	8	54	53	82	98	170	230	1147	2074
10.	DMR-ESR-W (C1)	3163	10	55	52	65	94	183	255	910	1839
11.	DMR-ESR-Y (C1)	3150	11	53	53	81	98	186	222	1127	1886
12.	TZESR-W (C2)	3430	6	51	53	94	99	173	213	1583	1897
13.	TZESR-Y (C2)	3740	3	54	53	80	100	194	226	1373	2148
14.	Pool 16 (IITA)	3727	4	51	49	89	96	214	254	1273	1832
15.	Jaune Flint de Saria	2457	15	45	46	73	80	185	226	985	1330
	Moyenne générale	3314	—	52	51	81	96	189	233	1203	1861
	C.V. %	22		5		14		9		20	
	Prob. de F										
	Systéme de billonnage	< 0.001		0.12		0.02		0.005		0.002	
	Variétés	0.02		< 0.001		0.0001		0.002		< 0.001	
	S x V	0.12		0.52		0.032		0.26		0.21	
	PPDS (5%) pour comparer les variétés:										
	Moyennes	731		2.5		12		20		276	
	Au même systéme de billonnage	1034		3		17		28		391	

Table 3 Rendement en grains (humidité 0%), ses composantes et jours à 50% de soie des variétés testées dans RUVT-1 sous 2 niveaux de sécheresse, Kamboinsé, Burkina Faso, 1985.

N°.	Noms des variétés	Rendement kg/ha		Jours à 50% de soie		% d'egrenage		Poids de 1000 graines (g)		N° graines/m2	
		Stress		Stress		Stress		Stress		Stress	
		Elevé	Moindre	Elevé	Moindre	Elevé	Moindre	Elevé	Moindre	Elevé	Moindre
1.	Synthetic C	2746	4901	51	51	76	80	155	197	1778	2500
2.	EV Gusau 81 Pool 16	3372	5018	47	46	80	83	169	238	1997	2111
3.	EV 8431 SR	3579	5070	46	44	81	83	188	220	1906	2305
4.	M. G. 82 TZESR-W	3108	4589	49	50	80	82	148	183	2095	2513
5.	XL 73	2645	4571	52	51	79	81	133	160	1974	2856
6.	SIDS 8245	3753	4502	48	49	80	82	172	217	2168	2071
7.	Capinopolis 8245	3319	4740	48	49	81	84	178	225	1885	2121
8.	Compuesto S. Precoz	3458	4749	41	40	81	83	192	248	1801	1918
9.	Safita 2 RE	2813	4587	49	49	80	83	147	217	1914	2112
10.	Safita 104 RE	4130	4733	41	42	85	85	193	225	2138	2099
11.	Jaune denté de Bambey	3136	4632	49	50	80	83	152	201	2059	2297
12.	Jaune Flint de Saria	3695	4444	41	41	84	84	190	219	1942	2035
	Moyenne générale	3313	4711	47	47	81	83	168	213	1871	2245
	C.V. %	11		3		1		8		9	
	Prob. de F:										
	Systéme de billonnage	0.002		0.87		0.004		0.003		0.007	
	Variétés	0.008		< 0.001		< 0.001		< 0.001		< 0.001	
	S x V	0.01		0.78		0.04		0.03		< 0.001	
	PPDS (5%) pour comparer les variétés:										
	Au même systéme de billonnage	609		2		1.5		21		265	
	Aux différents systèmes de bil.	711		2		1.7		25		283	

Table 4 Moyenne de rendement en grain, jours à la floraison et hauteur de plante de 20 variétés de maïs. Essais de stress, Kamboinsé 1984.

Entrées	Origine	Rendement en grain kg/ha	Rendement en grain Rang	Jours à 50% de formation de soie	Hauteur de plante (cm)
1. Koudougou local	Burkina	491	5	48.0	118
2. Kamboinsé local	"	112	20	60.0	115
3. Diapaga local	"	413	11	53.8	123
4. Raytiri local	"	505	4	47.2	132
5. Pabre local	"	459	8	53.2	121
6. Loumbila local	"	534	1	49.0	136
7. Jaune Flint de Saria	Burkina/IRAT	394	12	48.6	116
8. Pool 34 QPM	CIMMYT	317	16	60.5	114
9. Early Yellow	Ghana	220	18	61.0	113
10. Safita-104	SAFGRAD/IITA	475	6	51.0	120
11. TZE-4	SAFGRAD/IITA	389	13	53.8	122
12. Safita-2	"	320	15	59.5	126
13. Temp x Tropical 42	"	508	3	58.7	132
13. DMR-Y	IITA	422	9	58.6	132
15. TZESR(W)	IITA	273	17	52.5	148
16. Pirsabak(1) 7930	CIMMYT	355	14	57.5	122
17. TZE 16 Across-W	SAFGRAD/IITA	422	10	53.2	115
18. Composite 77 BD	Senegal	177	19	—	107
19. Pool 18 (SAFGRAD)	SAFGRAD/IITA	524	2	53.7	112
20. EV. 8188	Tanzania	471	7	50.0	122
	Moyenne	389		—	122
	PPDS (5%)	154		—	12
	C.V. (%)	49.2		—	12.4

Table 5 Rendement kg/ha, ses composantes et jours à 50% de la floraison emelles des variétés testées dans KT 38, Kamboinsé, Burkina Faso, 1985.

No.	Noms des variétés	Rendement kg/ha		Jours à 50% de floraison femelle		No. d'épis 100 plants		Poides 1000 graines (gr.)		No. graines/m2	
		Stress		Stress		Stress		Stress		Stress	
		Elevé	Moindre	Elevé	Moindre	Elevé	Moindre	Elevé	Moindre	Elevé	Moindre
1.	Local Koudougou	2020	2610	48	47	98	101	157	180	1273	1440
2.	Local Kamboinsé	1837	3179	60	59	91	116	147	178	1246	1793
3.	Local Diapaga	2083	2592	56	57	99	110	161	181	1285	1429
4.	Local Raytiri	2005	2467	49	50	102	106	168	183	1194	1324
5.	Local Pabré	2055	2265	59	60	99	107	149	157	1377	1451
6.	Local Loumbila	2204	2899	55	56	105	94	154	183	1423	1584
7.	J.F.S.	1813	2656	50	54	99	124	166	190	1077	1398
8.	Pool 34 QPM	1856	3466	60	60	102	112	138	185	1364	1873
9.	Early Yellow	2262	3279	61	62	98	114	148	174	1529	1887
10.	Safita 104	2504	2838	50	53	98	97	169	186	1480	1521
11.	TZE-4	2102	3349	56	56	113	121	157	194	1327	1728
12.	Safita 2	2212	4005	60	59	97	118	159	201	1396	1996
13.	Temp x Trop N° 42	2559	4314	58	58	105	112	159	204	1610	2109
14.	DMR-Y	2414	3977	58	59	95	106	160	198	1512	2007
15.	TZESR-W	2228	3801	59	59	102	112	148	198	1484	1917
16.	Pirsaback(1) 7930	2062	3677	57	58	108	135	153	191	1352	1919
17.	TZE 16 Across W	1919	3115	59	62	99	121	142	170	1333	1825
18.	Composite 77 BD	1736	3130	66	66	89	114	150	185	1156	1700
19.	Pool 18 (SAFGRAD)	2043	3202	56	56	100	121	169	216	1196	1487
20.	EV 8188	2139	2464	49	54	104	111	184	203	1155	1216

Table 5 Suite

No.	Noms des variétés	Rendement kg/ha		Jours à 50% de floraison femelle		No. d'épis 100 plants		Poides 1000 graines (gr.)		No. graines/m2	
		Stress		Stress		Stress		Stress		Stress	
		Elevé	Moindre	Elevé	Moindre	Elevé	Moindre	Elevé	Moindre	Elevé	Moindre
	Moyenne générale	2103	3164	56	57	100	113	157	188	1338	1680
	C.V. %	18		4.4		12		7		16	
	Prob de F										
	Systèmes de billonnage	0.002		0.17		< 0.001		< 0.001		0.02	
	Variétés	< 0.001		< 0.001		< 0.001		< 0.001		< 0.001	
	S x V	< 0.001		0.1		0.018		< 0.001		0.02	
	PPDS (5%) pour comparer les variétés										
	Au même système de billon.	545		2.9		15		14		282	
	Aux différents systèmes de billonnage	714		3.2		15		15		375	

stress de sécheresse Temperate x Tropical 42 (V13), Safita 2 (V12) et Pirsaback (1) 7930 (V16) ont donné des rendements significativement plus élevés que Local Kamboinsé (V2).

Dans le dernier groupe de maturité DMR-Y (V14) a significativement surclassé composite 77 BD (V18) au niveau élevé de stress de sécheresse. Au niveau moindre de stress DMR-Y (V14) et TZESR-W (V15) ont également donné des rendements significativement plus élevés que celui de Composite 77 BD (V18). En rapprochant les données de 1984 (Fig. 4) et les données de 1985 (Fig. 5) on constate que la tendance est conservée pour certaines variétés: Temperate x Tropical n° 42 (V13) qui, pour les 2 années a donné des rendements performants aux deux niveaux de stress de sécheresse et Composite 77 BD (V18) qui au contraire est resté stable pour les bas rendements aux deux niveaux de stress de sécheresse.

Ainsi, selon le rendement, Safita 104 (V10) du 1er groupe et Temperate x Tropical 42 (V13) du 3e groupe se sont montrées plus prometteuses pour la résistance à la sécheresse. Safita 104 n'a pas montré une réduction significative du nombre d'épis par plant et du nombre de graines par m2 à cause de la sécheresse et a montré une réduction seulement de 9% du poids de 1000 graines (Tableau n° 5). Temperate x Tropical 42 (V13) n'a également pas souffert de la sécheresse quant au nombre d'épis par plant mais le poids de 1000 graines et le nombre de graines par m2 ont été significativement réduits par la sécheresse de 22 et 24% respectivement.

Local Kamboinsé (V2) et Composite 77 BD (V18) se sont montrées relativement susceptibles à la sécheresse comparées aux variétés des mêmes groupes. Local Kamboinsé (V2) a vu le nombre d'épis par plant, le poids de 1000 graines et le nombre de graines par m2 réduits par la sécheresse de 21%, 17% et de 31% repsectivement. Composite 77 BD (V18) aussi a été significativement affecté par la sécheresse sous l'angle du nombre d'épis par plant, poids de 1000 graines et nombre de graines par m2 se traduisant par des réductions de 22%, 19% et 32% respectivement (Tableau n° 5).

Amelioration de population

Matériel et méthode

Les travaux sur la résistance à la sécheresse ont commencé durant la saison sèche 1982 et se sont poursuivis en 1983, 84 et 85. Pool 16 (matériel tropical précoce blanc denté développé par le CIMMYT) a été identifié comme matériel tolérant la sécheresse, comparé à 26 matériels avec lesquels il a été testé dans plusieurs conditions de stress de sécheresse, avec irrigation contrôlée. Au cours de la saison pluvieuse 1983 des familles plein-frères ont été développées puis testées au cours de la saison sèche suivante. En 1984, 219 familles ainsi que 6 témoins ont été semés dans un dispositif de split-plot avec deux systèmes de billonnage (billons simples et cloisonnés), le système de billonnage représentant les parcelles principales et les familles les sous-parcelles avec 2 répétitions. Chaque famille (sous-parcelle) comportait une ligne de 2,5 m de long avec deux plantes par poquet. L'espacement entre les poquets et les lignes était respectivement de 0,5 et 0,75 m. En utilisant les systèmes de billonnage chaque famille a été testée dans 2 environnements de stress de sécheresse (plus élevé et plus bas).

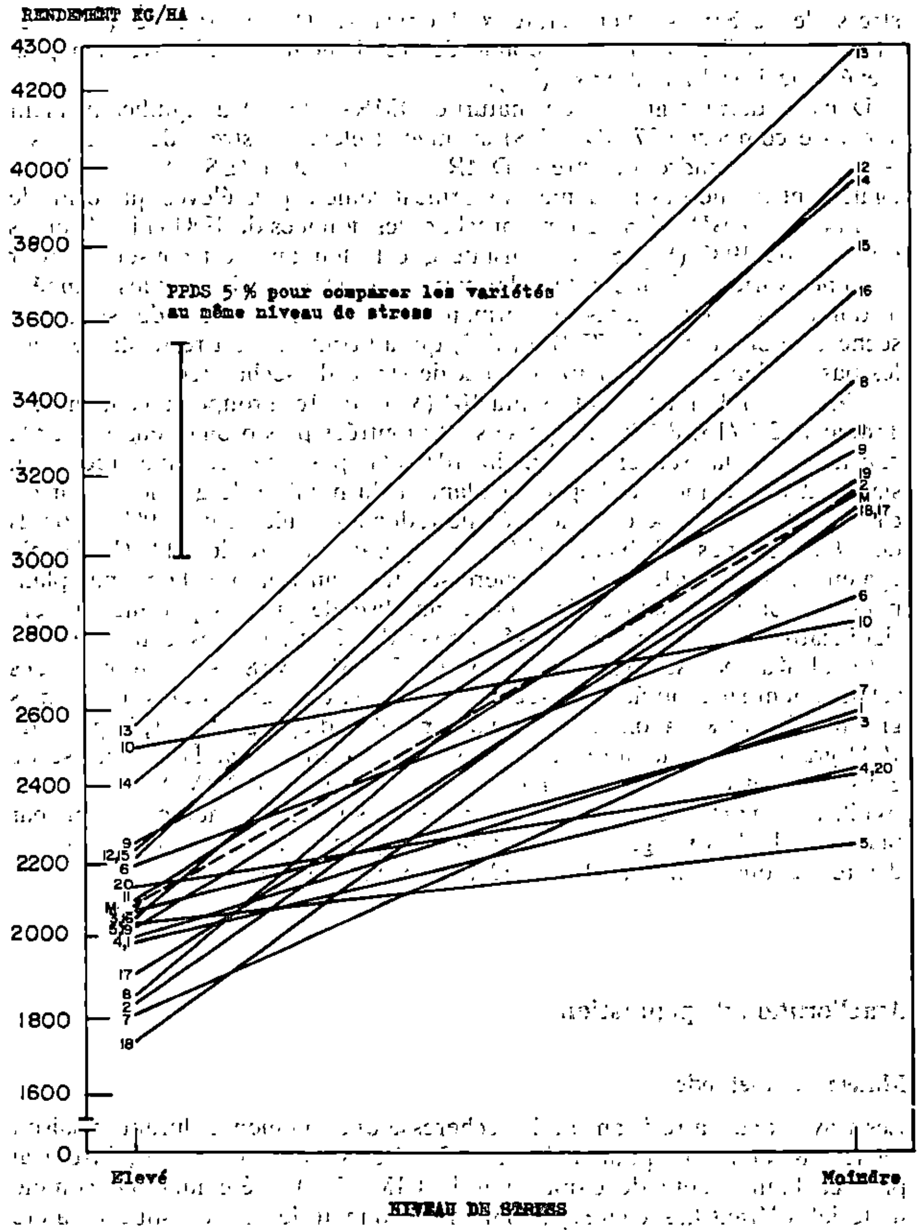

Figure 5 · Rendement de 20 variétés testées sous 2 niveaux de stress, Kamboinsé, Burkina Faso, 1985.

Résultats et discussions

En 1984, l'essai n'a reçu que 227,4 mm de pluie. Cinq petites irrigations de 8 mm chacune ont été indispensables afin d'assurer le rendement en grain. Le F test a été statistiquement significatif (5%) pour les systèmes de billonnage et pour les familles. L'interaction familles x systèmes de billonnage n'a été significative qu'au seuil 10%. Comme l'erreur expérimentale était très élevée (C.V. = 89%), cela laisse penser que la performance relative des familles n'a pas été la même sous les deux niveaux de sécheresse.

Dix familles ayant une performance de rendement meilleure à celle de la moyenne de la population a' chaque niveau de stress ont été sélectionnées en vue de développer une variété expérimentale résistante à la sécheresse. Sept autres familles ont été sélectionnées sur la base de leur rendement plus faible que celui de la moyenne de la population dans les conditions de stress plus élevé et de leur rendement plus élevé que celui de la moyenne de la population dans les conditions de stress moins élevé (Fig. 6a et 6b) afin de développer une autre variété expérimentale dite susceptible à la sécheresse.

Pour la régénération de la population, afin de démarrer le cycle 2 de sélection, 16 autres familles dont la moyenne de rendement était supérieure à celle de la moyenne de la population dans les deux conditions de stress de sécheresse (respectivement 275 kg/ha et 487 kg/ha) sous stress plus élevé et stress moindre en comparaison avec la moyenne de la population (140 et 331 kg/ha) ont été sélectionnées et ajoutées aux 10 meilleures familles déjà sélectionnées. Cela a fait 26 familles pour la poursuite de la sélection.

Evaluation du Progres

EV Pool 16 DR

Matériels et Méthode

En 1985 la variété EV 84 Pool 16 DR (résistante à la sécheresse), EV 84 Pool 16 DS (susceptible à la sécheresse), Pool 16 DR C0, Pool 16 DR C1 ont été testées avec 5 autres matériels signalés résistants à la sécheresse: XL 73, Latente x Latente, Tuxpeno DR C6 (la fraction précoce), Imbred german line x Safita 104, Michuacan 21 et un témoin local (JFS). Le même dispositif a été utilisé mais en 6 répétitions et des parcelles de 4 lignes distantes de 0,75 m, un plant par poquet distant de 0,25 m sur les lignes.

Résultats et Discussions

Le Tableau n° 6 montre le rendement moyen, ses composantes et jours à 50% de formation de soie des 10 variétés testées dans cet essai et la Fig. 7 illustre les rendements en grains sous les deux niveaux de stress de sécheresse. Pour le rendement, des différences hautement significatives ont été observées entre les variétés et les deux niveaux de stress de sécheresse (2124 kg/ha pour les billons simples et 3524 kg/ha pour les billons cloisonnés. L'interaction Variétés x Système de billonnage n'a été significative qu'à 12%. Aucune différence statistiquement significative n'a été observée entre EV 84 Pool 16 DR (V1), EV 84 Pool 16 DS (V2), Pool 16 DR (C0) et Pool 16 DR (C1). Le rendement le plus élevé a été obtenu pour Pool 16 DR (C1) (3408 kg/ha).

Conclusion

Le méthode d'utiliser les billons simples et cloisonnés pour évaluer la réaction des génotypes et familles de maïs à la sécheresse permet de tester les matériels dans les conditions réelles de culture avec un aménagement approprié. Cependant, cette méthode est loin d'être parfaite, elle peut être

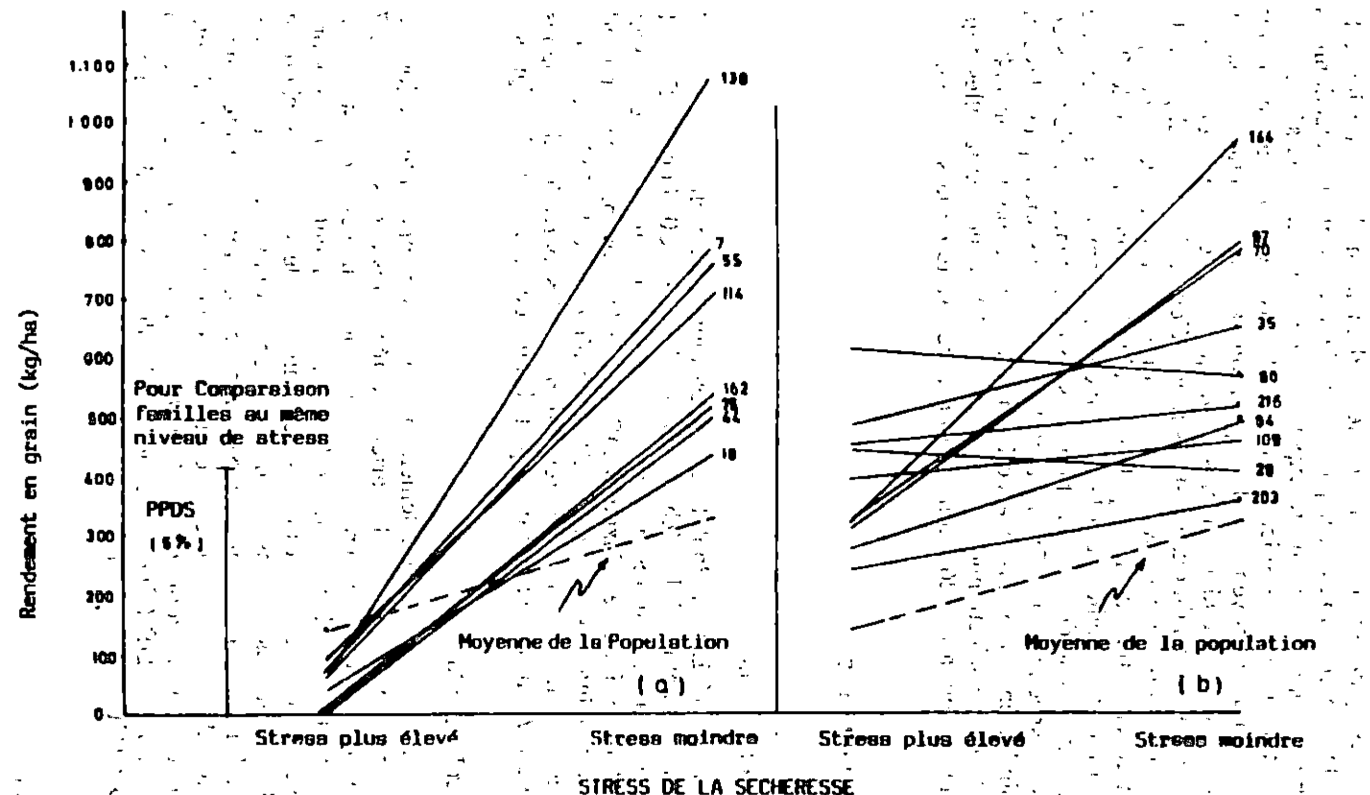

Figure 6 (a) Rendement en grain de 8 familles full sibs de maïs de performance respectivement inférieure et supérieure à celle de la moyenne de la population dans des conditions de stress de la sécheresse plus élevé et moindre. (b) Rendement en grain de 10 familles full sibs sélectionnées de maïs de performance supérieure à celle de la moyenne de la population dans les deux conditions de stress. Pool 16 (219 familles) Kamboinsé, (Burkina Faso) 1984.

Table 7 Rendement en grains (humidité 15%), ses composantes et jours à 50% de formation de soie des variétés testées dans EVT Pool 16 DR, Kamboinsé (Burkina Faso), 1985.

N°	Nom des variétés	Rendement moyen kg/ha	Rang	Jours à 50% de soie		N° Epis/100 plantes		Poids 1000 graines (g)		N° grains/m2	
				Stress		Stress		Stress		Stress	
				Elevé	Moindre	Elevé	Moindre	Elevé	Moindre	Elevé	Moindre
1.	EV 84 Pool 16 DR	3107	4	52	50	91	92	184	232	1311	1643
2.	EV 84 Poool 16 DS	3141	3	52	52	87	98	187	247	1173	1650
3.	Pool 16 DR (C0)	3232	2	52	51	88	99	181	228	1323	1791
4.	Pool 16 DR (C1)	3408	1	51	51	93	100	182	239	1331	1826
5.	Tuxpeno DR (C6)	3061	5	54	54	89	96	153	203	1432	1934
6.	Latente x Latente	2992	6	53	53	95	92	160	193	1510	1826
7.	XL 73	2624	7	55	54	79	89	144	187	1317	1764
8.	Muchuacan 21	1949	10	57	56	60	76	161	205	850	1229
9.	Safita 104 x G. II.	2191	9	46	47	70	71	185	209	1015	1207
10.	Jaune Flint de Saria	2525	8	46	45	88	94	178	212	1112	1438
	Moyenne générale	2824		52	51	84	91	172	216	1237	1631
	C.V. %	20		3		12		8		19	
	Prob de F										
	Système de billonnage	0.001		0.11		0.065		<0.001		0.007	
	Variétés	< 0.001		< 0.001		< 0.001		< 0.001		< 0.001	
	S x V	0.12		0.89		0.52		0.16		0.92	
	PPDS (5%) pour comparer les variétés										
	Moyennes	457		1.5		8		13		219	
	Au même système de billonnage	647		2		11		18		310	

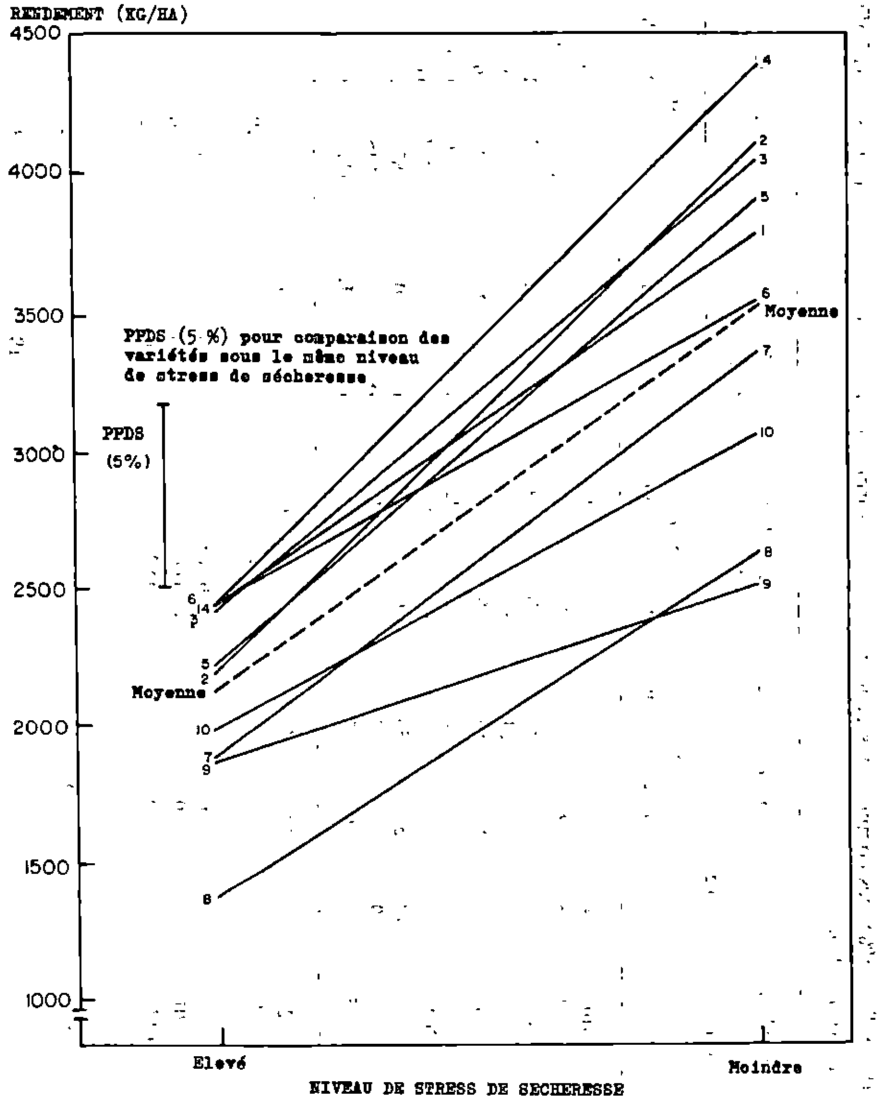

Figure 7 Rendement en grains de 10 variétés testées dans EVT Pool 16 DR sous 2 niveaux de stress de sécheresse à Kamboinsé, Burkina Faso, 1985.

améliorée. Dans nos conditions de manque de terrains uniformes et de facilités d'irrigation, il est difficile de proposer une meilleure alternative. Bien qu'il soit possible de faire du progrès utilisant cette méthode, elle reste cependant étroitement dépendante des conditions climatiques. Des années comme 1984 avec une pluviométrie très faible, les plantes sur billons cloisonnés et simples sont toutes sujettes à une très forte sécheresse. Des années comme 1985 avec des pluies abondantes au mois de Juillet, de stagnation d'eau dans les parcelles à billons cloisonnés peuvent affecter les plantes particulièrement si les semis ont été faits sur des vieux billons confectionnés l'année précédente. Ainsi, pour créer des conditons effectives afin de tester le matériel sous deux niveaux (élevé et moindre) de sécheresse, l'irrigation contrôlée s'avère indispensable pour apporter l'eau au moment qui'il faut et à doses contrôlées et précises.

Les données présentées ont montré que dans certains cas il y a interaction significative Variétés x Niveau du stress de sécherasse, dans d'autres cas pas d'interaction. Ces essais devraient être reconduits afin d'établir si de telles interactions sont significatives ou seulement occasionnelles. Dans ce dernier cas, pour raison d'économie et d'efficacité, il serait plus approprié de tester les matériels sous un seul niveau (élevé) de sécheresse. Si au contraire, l'interaction genotypes x niveau de stress de sécheresse est significative, tester les génotypes sous deux niveaux ou plus de sécheresse serait plus approprié, dans la mesure où on cherche à développer des variétés qui peuvent performer raisonnablement bien sous sécheresse mais donnant des hauts rendements sous bonnes conditions d'humidité.

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17 Maize production and improvement in Zambia

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Introduction

In Zambia maize is the most important cereal crop since it is the staple food of almost the entire country. It is grown in most parts of the country except in some exceptionally wet, dry or infertile soils where sorghums, millets or cassava are more adapted. Maize is grown on an area of over 580,000 hectares of the 58.6 million hectares of arable land. Current production (1985 season) is 1,123,290 tons (table 1), of which about 50% was marketed through established agencies. Forty per cent of the crop production comes from commercial farmers and the rest from emergent or small-scale farmers. There is an increase in maize production in the country due to genetic improvement (new hybrids and varieties) and better agronomic management like improved weeding, fertilization and land preparation.

The principal provinces of maize production in Zambia are Southern, Central, Eastern and Northern. Maize is planted from the middle of October in the Northern part of Zambia to middle December in the Southern Province. The most important factor determining planting date is soil moisture. The period between 1980-1983 was extremely dry. Under normal growing season Zambia receives an average rainfall of 850 mm. However during this period of three growing seasons (1980-1983) the average rainfall was low, around 600 mm. Due to this low rainfall and its poor distribution in the growing season, the country experienced very low maize production.

Maize research in Zambia is under the department of Agriculture in the Ministry of Agriculture and Water Development. It is one of the thirteen commodity research teams in the Research Branch in the Department. Maize Seed Production and distribution is the responsibility of the Zambia Seed Company (Zamseed) which was established in 1981. Commercial maize marketing is carried out by the National Agriculture Marketing Board (NAMBOARD) and Cooperative Unions.

Table 1 Maize Yield and Production Area.

Year	Total production (tons)	Average Yield (T/ha)	Total Marketed (t)	Total Production Area
1983	935,280	1.71	521,164	546,700
1984	871,740	1.71	571,287	506,500
1985	1,123,290	1.98	640,000	566,900
1986*	1,530,000	2.60	765,000	580,000

* Estimated for the 1985/86 season.

Maize Research Programme

Agronomic research on maize started during early fifties. The breeding programme started after Independence in 1964. During the late fifties and early sixties, research concentrated on agronomy alone with emphasis on the requirements and limiting factors for maize growing in the country. Early trials concentrated on determining basic nutrition requirements, population densities and planting dates. The problems of soil acidity were found to be limiting maize yields. At the inception of the breeding programme (1965), the then maize breeder Mr. J.B. Abington collected various maize germplasm from various countries including Ecuador, Mexico, Kenya and Zimbabwe. The collections included over 500 different maize varieties and Inbred lines. Out of these, 63J was selected and used as a male to cross with SR52 and produced the first Zambian hybrid variety in 1970 which was named ZH1.

After the Breeder's attendance of the first, second and third East African Cereals Research Conference, a long term programme was initiated with the aim of producing good yielding and stable maize varieties better than SR52, SR11 and SR13, and to develop suitable varieties for both rural and commercial requirements. As a result of this, two maize populations were developed between 1969 and 1970, these were Zambian Composite A (ZCA) developed from Hickory King plus seventeen Inbred lines from the Zambian programme. The other variety was ZUCA (Zambian Ukiriguru Composite A) developed in Tanzania as UCA and crossed to Zambian germplasm. A composite from Ecuador (EC573) was improved and later used for commercial production.

When Mr. Abington left Zambia in 1973, an agronomist/breeder took over the programme. At this point the emphasis shifted from quantitative to qualitative characters of the breeding programme in collaboration with CIMMYT–MEXICO. Efforts were directed towards protein quality, cytoplasmic male sterility, dwarfing genes (Br_2) and the testing of foreign varieties for agronomic suitability. This lack of continuity in maize breeding programme was one of the reasons why SR52 has been in production for over 22 years. Even then the parents of SR52 were contaminated due to inadequate seed maintenance resulting in yield loss of 15-20%.

The Current Maize Research Programme

The current maize research programme is nationally coordinated by a senior maize breeder, as part of the cereals commodity research team with the National Cereals Coordinator who is under the administrative control of the Chief Agriculture Research Officer. The main research work is carried out at Mount Makulu Central Research Station, with multilocation testing at other provinces and regional research stations.

The present maize research programme is a continuation of a comprehensive breeding programme started in 1978 by a Yugoslav maize breeder who was joined by two BSc. graduates in the same year. The programme currently integrates four disciplines, these are:

A) Maize Breeding which includes
   i Population development and improvement through half-sib method;

ii Inbred lines development and improvement through pedigree and backcross methods.
iii Testing of combining ability of newly developed inbred lines through verification trials.

B) Maize Protection which includes
  i Maize pathology
  ii Maize entomology
C) Maize Agronomy
D) Maize Seed production and maintenance of elite inbred lines.

Maize Breeding

Population Development and Improvement

Improvement of source material for the released Varieties, MMV400 and MMV600 continues, along with the improvement of other promising populations. Currently p (2) 7930, EV80976, ZUCA, Across 7844, population 10, population 43, EC 573 and POZA RICA 7832 are under selection, through recurrent halfsib method. MMV400 an open pollinated variety and its source population p (2) 7930 are tolerant to drought through at least two important factors (i) early maturing or ESCAPE if the rainy season is short, and (ii) good synchronization of pollen shed and silking which allows pollination even with considerable moisture stress. Major improvements in streak resistance have been obtained in the originally susceptible populations of ZUCA, EC573, Across 7844 and POZA RICA 7832, by intense selection under high levels of natural and encouraged streak virus attack. New promising materials are being identified to determine whether they should be chosen for improvement, and serve as sources of inbreds and variety crosses.

Inbred Line Development and Improvement

The large proportion of the maize breeding effort is currently devoted to inbred line development and improvement. The Inbred line – hybrid development and improvement programme's major objectives are:

i to select improved source populations
ii Develop new Inbreds
iii to develop shorter maturing, stable yielding hybrids.
iv Improvement of established Inbred lines
v Purification of the contaminated parents of SR52, and
vi to evaluate other improved commercial maize hybrids. Currently there are about 17,000 inbred lines and sublines involved in development and improvement of inbreds and hybrids through pedigree and backcross methods of selection. Twenty percent of the 500 Inbred lines tested last season (1985/86) showed good combining ability for yield and other characters, hence several new hybrids were advanced to preliminary trials.

Maize Protection

One of the major emphasis of the maize breeding programme is to breed for pest and disease resistant maize genotypes. Great effort is put on pathology and entomology which has just been started. The maize pathology objective is to screen large numbers of maize germplasm to identify sources of resistance to major diseases. The main diseases at which great effort is directed are:

i Maize streak virus
ii cob rots and
iii leaf blight (*Helminthosporium turcicum*)

An entomologist is working on the rearing of leaf hopper (*Cicadulina mbilla*) which is the Vector for Streak virus.

The multilocation disease resistant variety trial of 1984/85 season showed that eight entries out of twelve had a score of 1.5 or less indicating excellent resistance to streak virus attack; two of them showed very little streak virus incidence. Out of 510 lines screened for streak resistance, 140 lines had no virus infection and an additional 214 lines had very little infection. Out of 140 germplasm lines screened, 66 lines have shown high levels of resistance to cob rots with field Inoculations. On leaf blight inoculation, MM502 showed less infection than other two entries (MM752 and MMV 600).

Maize Agronomy

Investigation on population densities, fertilizer levels and planting dates have been the main focus. One University of Zambia BSc. graduate has just been recruited to the post of maize agronomist. There are so many agronomic problems which need to be investigated, for example multilocation trials on densities, fertility levels, planting dates, weeding patterns and cropping systems (e.g. rotations or Intercrop). All these would give an indication of the response of the new hybrids and varieties. Investigations of the response of new varieties to soil acidity is also needed, as this is a major problem in the Northern and Northwestern part of Zambia. The suitability of various new maize hybrids in different rural communities still needs more emphasis.

Seed Production

The production of hybrid varieties of maize requires development and crossing of inbred lines selected to combine characters into the hybrid progeny. The methods of production and maintenance of inbred lines vary among breeders, but always some from of selfing or sibbing or both, and selection are used. To maintain purity of our commercial inbred lines selfing was used for Breeders Seed production and sibbing for pre-basic and basic seed production to obtain the required quantity for certified seed production. Table 2 shows the 1985/86 production area.

Table 2 1985-86 Seed Production Area (Ha)

Hybrid (variety)	MM 501	MM 502	MM 504	MM 601	MM 603	MM 604	MM 752	MMV 600	MMV 400	Total
Ha.	10	40	318	458	578	590	380	295	88	2757

Achievements

Zambia experienced severe drought conditions for three successive seasons from 1980-1983 and the conditions made it possible to screen materials under naturally dry conditions and cross them to produce drought tolerant hybrids or populations. Multilocation testing for adaptability was used to select drought tolerant and high yielding genotypes at various agro-ecological zones. Hybrids developed during this period have good pollen shed and silk synchronization, and were therefore much more tolerant to drought at tasselling time than SR52, which had a long silk delay.

The efforts initiated in 1978 yielded satisfactory results in Zambia in a short time (i.e. in less than eight years). One of the greatest achievements was the release of a purified form of SR52. Table 3 compares the performance of SR52 from Zimbabwe, (Zi) SR52, old, Zambian (Za) and the new version called MM752, across five locations. The yield performance of the new version of SR52 (MM752) has equalled that of SR52 from Zimbabwe (Zi). The implication of this is the importance of proper seed maintenance, and purification. For SR52 purification a simple ear-to-row method was used, and "true-to-type" plants and/or cobs were selected and selfed each time for five generations, and recombinations were being evaluated in the 1980/81 season.

Table 3 Comparison of yield (t/ha) of MM752 Vs SR52 (Zi) and SR52 (Za): Average of two years across five locations

Hybrid	Mt. Makulu	Mazabuka	Magoye	Msekera	Kabwe	Mean
MM752	5.95	5.01	5.86	9.39	10.55	7.35
SR52 (Za)	5.41	4.26	4.42	8.32	8.41	6.16
SR52 (Zi)	5.43	4.72	6.61	10.29	10.61	7.53
% Increase MM752 (Vs) SR52 (Za)	9.08	14.97	24.57	11.40	20.33	16.19

The second achievement of greater importance was the development and release of seven new hybrids and two open pollinated varieties. The great number of released varieties provided alternatives for the needs of various agro-ecological requirements of the country. Table 4 shows the characteristics of the new varieties. It is interesting to note from table 4 that the new hybrids have two major advantages over MM752 (SR52), drought tolerance and streak virus resistance. The impact of these achievements has been that

i Zambia does not import any certified maize seed,

ii Seed production has saved the country foreign exchange,
iii Marketed maize and maize retained on farms has increased
iv The Seed Company is well established financially through sales of these new maize hybrid seeds.

Table 4 Characteristics of newly Developed Maize Varieties (Hybrids and Open-pollinated)

Variety	Yield (t/Ha)	Ear height	Days to 50% silk	Maturity (Days)	Resistance to Streak	Drought
MM501	6.43	84	65	120	Good	Excellent
MM502	6.66	86	70	130	Excellent	Excellent
MM504	7.37	86	66	125	Good	Good
MM601	8.66	110	70	130	Good	Good
MM603	8.36	100	70	130	Excellent	Good
MM604	8.73	100	70	135	Good	Good
MM606	6.62	100	68	135	Fair	Good
MM752	7.35	120	75	150	Poor	Poor
MMV600	6.12	—	65	135	Good	Fair
MMV400	4.94	—	45	100	Fair	Excellent

Yields (t/ha) are means of five locations (Golden Valley, Kabwe, Msekera, Mansa and Mochipapa 1984/85 season).

Obstacles and Constraints on Research and Research Results

The achievements have been great in such a short a time but there were a lot of difficulties. At the start of the programme there was only one maize breeder with two BSc. graduate Assistants. The government did not allocate any budget for maize research for about two years, thus creating a major financial constraint resulting in heavy dependence for land and other resources from the Yugoslav farm (Maize Research Institute – Mazabuka). The poor transport situation made it difficult for breeders to move especially during planting, harvesting and pollination periods. Research activities have been relatively reduced at the Central Research Station due to the effects of cement production waste (dust) from a near by factory. The dust has raised the soil pH on research fields, and has greatly affected inbred lines development as soils show nutrients deficiency.

If the achievements are to be sustained there is need to increase and diversify storage and irrigation facilities. The maize research section has expanded its manpower from only one breeder to six breeders, two pathologists, one entomologist and one agronomist; but the facilities have remained the same since 1978. In order to handle thousands of breeding materials, there is need to have a big shed, dryers and adequate cold rooms. To perpetuate the programme of attaining two selfing generations per year, there is need to improve the irrigation facilities at the National Irrigation Research Station, 100 kilometers south of Lusaka. There is also need for improved farm mechanisation to enable proper land preparation for experimental fields.

To summarise, the constraints on research have been and still are

i. Finance
ii. Manpower

iii. Field mechanisation
iv.. Irrigation and storage facilities, and
v. Transport.

Technically, achieving goals like drought tolerance have been hard due to the difficulties of utilizing physiological traits to assess drought tolerance. However determination of drought tolerance has relied only on natural conditions through multilocation testing during drought periods.

On disease resistance, proper screening techniques for leaf blight (Ht) are still being investigated, however there is streak virus resistant germplasm available to combat this disease.

Linkages with Regional and/or International Research Centres

In Zambia entries are evaluated from various countries within the Eastern, Central and Southern Africa region, both to assess the country's own progress and to recommend suitable hybrids for import if needed. CIMMYT–MEXICO sends its breeding materials to be evaluated in Zambia, such materials have contributed to the release of the two varieties from EV 8076 and PR (2) 7930. Maize genotypes resistant to maize streak virus have been provided by IITA. The maize Research Institute in Yugoslavia, Belgrade, has and is still the corner stone of the present hybrid breeding programme.

The Maize Research Institute (BELGRADE–YUGOSLAVIA) has provided considerable material inputs and manpower.

The systematic maize breeding programme started in 1978 when the first Yugoslavia breeder took over the work. The programme continued under the Yugoslav support in 1981 with a new maize research coordinator from Yugoslavia. FAO has as well contributed a maize pathologist who arrived in July, 1980 to work on maize disease problems within the maize breeding programme. Financial and other material support is also provided to the programme from FAO. The FAO programme has expanded in developing disease resistant maize in Zambia. SIDA (Swedish International Development Agency) also provides support for research and manpower, and initiated the Zambia Seed Company. Finally US-AID began to support a project called ZAMARE (Zambia Agriculture Research and Extension Project) in 1982. The project's emphasis has so far been on the development and Improvement of open-pollinated varieties. The project has helped in the testing of hybrids and varieties in various locations.

High Priority Areas for Research

Heterogeneous open-pollinated germplasm is a base from which a few improved populations are developed and released for commercial production and Inbred lines extraction. As improvement continues these populations are involved in various variety production. The process of hybrid development is built on these improved populations. Top crosses, double crosses, three-way and finally single cross hybrids in order of decreasing genetic diversity form a pyramidal type of the national's breeding programme. The implication is that for any progressive breeding programme, the goal must be to produce hybrids, and stabilise at some type of hybrids e.g. three-way as it suits the country's expenses on seed production.

Zambia is going through phases of population development and improvement, inbred-hybrid development and improvement. Maize varieties suitable for various agro-ecological zones have been developed, with each zone having its own constraints for maize production. Zone I covers Northern, Luapula, Northwestern, Copperbelt provinces and part of Western province; this zone receives 1000 mm and above rainfall and has a growing season stretching up to 180 days. The priority for breeding is to develop late, streak resistant varieties, which have as well tolerance to acidity. Zone II has moderate problems and is the main maize growing area, this covers central, Lusaka, Eastern, Southern and part of Western provinces. This Zone receives 800-1000 mm of rain per season and has the growing season of 150 days. Most of the newly released hybrids are suited for this zone. Zone III receives less than 800 mm of rain and has 120 days as a normal season, since the season is short, the priority is to breed drought tolerant, short maturing maize varieties. The priority areas in agronomy should be investigation of the responses to densities, fertilizer levels, maturity dates, cropping patterns, weeding; and planting dates, for the newly developed hybrids and varieties.

Pathology research should continue to emphasize screening of breeding materials for resistance to maize streak virus, cob rots, and *Helminthosporum turcicum* leaf blight. Entomology research, though in its early stages should, assess yield losses due to stalk borer and other insect pests important in Zambia, in addition to rearing the leaf hopper for streak virus screening.

18 Breeding Maize for the Semi-arid Areas of Kenya

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Abstract Only about thirty per cent of the total land area of Kenya can be considered to be arable although agriculture is the main-stay of Kenya's economy with over ninety per cent of her people relying on agriculture for their livelihood.

In the semi-arid areas, which comprise about a half of Kenya's arable portion, agricultural production is seriously hampered by scanty and unreliable rains that are very poorly distributed during crop growth. The majority of the farmers are small scale and operate at a predominantly subsistence level. Among the crops cultivated in this dry area maize is by far the most widely cultivated cereal and the most important food crop in the country. Inadequate rainfall imposes an overriding constraint on cultivation of crops inappropriately adapted to drought. This crop however remains the most preferred cereal in these semi-arid regions.

A maize improvement programme initiated in 1956 at Katumani Research Station in Eastern province has developed and released several early maturing and generally well adapted varieties that have proved very popular with farmers even outside the target area; Katumani composite B maize is now being cultivated in many parts of Kenya and also in neighbouring countries of East and Central Africa.

The paper examines the progress made by this breeding programme and briefly reviews some of the major problems encountered. The success of the programme is attributed partly to its simplicity and the presence of an efficient seed company which has played a very crucial role in Kenya's maize industry.

The paper concludes with a brief discussion on how maize breeding research is expected to proceed in conjunction with other disciplines, as the cultivation of the cereal is taken to areas hitherto considered too dry for maize.

Introduction

Kenya's economy is basically agricultural with over ninety per cent of the population relying on agriculture for their livelihood. Only about 20 per cent of the country's total land area can support high agricultural productivity whilst out of the remaining 80 per cent only a third has potential for rainfed farming. This latter fraction is commonly referred to as semi-arid.

The country can be divided into three general agroecological categories for arable agricultural purposes as shown in Table 1.

The semi-arid areas occupy agroecological zones 4 and 5 and comprise over 50 per cent of all the arable areas of Kenya, as shown in Figure 1. The larger part of these areas lies in the Eastern Province including the Coast and Rift-Valley Provinces.

In the semi-arid areas of Eastern Province, between 500 and 900 mm mean rainfall is received most of it falling in two distinct seasons; the long rains (March to May) and the short rains (October through December) although January and February may be quite wet in some years. Each of these seasons receives between 200 and 400 mm of rain on average

Table 1 Agroecological zones of Kenya.

Category	Type of Rainfall	Main agricultural activity	Primary Agroecological zones
1. Humid and Subhumid	Sufficient	Coffee, tea high yielding varieties of e.g. maize	2 and 23
2. Semiarid	Limited and irregular	High risk cropping	4 and 5
3. Arid	Erratic and inadequate	No rainfed cropping, (extensive grazing practised)	6 and 7

(Table 2) but precipitation is most erratically distributed. Crop production therefore faces not only scanty amount of rainfall most of the time but also uncertain amounts accentuated by uneven distribution during the growth season. This results in recurring episodes of reduced crop yields and sometimes complete crop failures (Njoroge, 1982).

Up until now, Eastern Province has been the only one of "Kenya's semi-arid provinces" having significant zones 4 and 5 farming communities. Cropping in semi-arid areas has been accompanied by a high rate of crop failure, a factor that is attributed largely to lack of appropriate technologies including non-availability of suitable cultivars. If available, such technologies could effectively alleviate chronic problems of soil-water shortages during crop growth.

Table 2 Average growing seasons' rainfall (mm) received at Katumani

Long rains[a]	Rainfall	Short rains	Rainfall[b]
March	81.9	October	41.9
April	141.8	November	147.4
May	66.4	December	86.4
Seasonal Average Total	290.1		275.7

[a] The long rains monthly average totals have been computed for a period of 29 years (1957-1985).

[b] Short rains figures for October are for 29 years (1957-1985) while those for November and December are for 30 years (1956-1985).

Maize in Kenya and in the Semi-arid Areas

Maize is believed to have been introduced in East Africa around the sixteenth century by Portuguese explorers although its proliferation in Kenya did not begin until around 1900. Within this relatively short period, it has rapidly supplanted the indigenous cereals, sorghums and millets, to a point where it

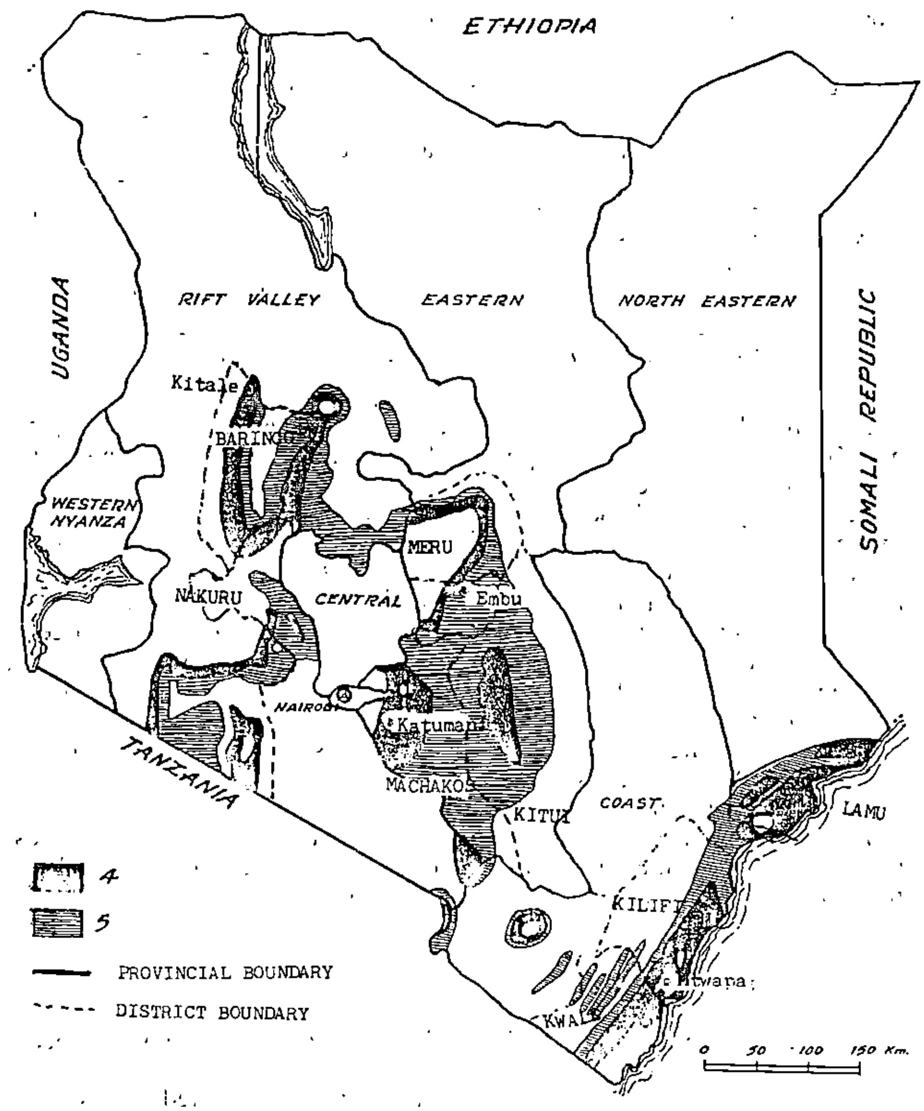

Figure 1 Agroecological Zones 4 and 5.

has become the most important food grain in the country. Maize is now the staple food of the vast majority of Kenyans and the most widely grown crop. As Ogada (1975) points out, estimates of the total value of the crop are difficult to make as only between 10% and 15% of all the maize produced in Kenya is marketed through official channels. Gerhart (1975) has observed that maize is the most important crop in Kenya's agricultural economy, in terms of its value or role as a basic dietary staple.

Table 3 demonstrates the importance of maize in the main semi-arid provinces, in terms of hectareage and tonnage relative to that of other important crops in a typical year, 1982.

Table 3 1982 maize production estimate figures compared with those of other principal crops from selectd semi-arid districts of Eastern, Rift-Valley and Coast Provinces (area in hectares and yield in metric tonnes)

Province	Maize		Other crops		Total		% Maize	
	Area	Yield	Area	Yield	Area	Yield	Area	Yield
Eastern	357.5	455.6	344.8	373.0	702.3	828.5	50.9	55.0
Rift Valley	153.2	171.5	92.9	159.8	246.1	331.2	62.3	51.8
Coast	51.6	42.8	24.0	117.4	75.5	160.3	68.3	26.7
Total	562.3	669.9	461.7	650.2	1023.9	1320.0	54.92	50.7

Source 1983 *Ministry of Agriculture and Livestock Development Annual Report*

The table shows that, in terms of area under cultivation, maize occupies over 50 per cent of the area cropped with the major crops and that a similar figure applies to the tonnage produced.

Farm surveys carried out in Eastern Province have confirmed that maize is the most preferred cereal although it is also the one that fails most frequently (Rukandema *et al.*; Audi and Jeza 1986). It fails mainly due to low quantities of rainfall received and which is very unevenly distributed, with a probability for a successful maize harvest being as low as 50 per cent (Lynam, 1978) or even 60 per cent (Anon, 1985) in places.

The vast majority of the farmers in this area operate at a subsistence level and, to them, yield increases that can be achieved with zero or low management changes, rather than with expensive inputs, are relevant (Whiteman 1981). Practices that reduce risk rather then maximising yields are to be preferred by the producers.

The need to have adapted maize cultivars with primarily stable yields under less-than-optimum growing conditions has been recognized for a long time in the Kenya maize breeding programmes.

Breeding Maize at Katumani

The general historical background to maize improvement in Kenya has been reviewed by Harrison (1970).

Maize breeding work for the semi-arid areas in Kenya started in 1956 with the main objective of developing fast maturing, drought escaping varieties that would fit into the existing bimodal rainfall pattern found in Eastern Kenya. During the growing season, rainfall is spread over a limited period of between 60 and 90 days.

The majority of maize varieties will not mature within this period. Experience at Katumani indicated that cultivars adapted to these conditions flower within about 60 days; the period when probability of receiving rainfall is reasonably high.

Early breeding policy at Katumani concentrated on development of synthetic and composite varieties because, synthetics and composites would have intrinsic ability to cope better with prevailing limited and unpredictable rains.

The programme aimed at achieving stabilized production through the development of early maturing genotypes that would escape dry seasons and produce acceptably high yields. Resistance to field diseases especially rusts, smuts and blights were also screened for, in the introduced materials.

This breeding programme at Katumani made steady progress despite a distraction in 1970's during the world wide surge for development of high lysine maize. The high lysine maize research programme was however abandoned in 1980 when it became clear that the efforts were not making appreciatable headway.

Maize Varieties Developed at Katumani

The initial breeding efforts at Katumani concentrated on finding a source for earliness locally but foreign materials had to be introduced when these attempts failed. Taboran, a variety obtained from Tanzania in 1957, flowered within 55 days from sowing, compared to a local land race, Machakos local white, which flowered in about 75 days. These two materials formed the base populations on which a dual series synthetic breeding programme was developed.

A schematic representation of how this programme progressed is shown in figure 2.

The two divergent synthetic series, termed "streams" by Harrison (1970), were developed with an objective of combining appropriate particular paired synthetics, one from each series, to constitute viable varieties.

This was first realized when an advanced cross between Katumani synthetic III and Katumani synthetic IV was released to the farmers in 1966 as Katumani composite "A".

Subsequently Katumani composite "B" was released in 1968 being an improvement of a cross between Katumani synthetic V and Katumani synthetic VI. These two composites had been preceded by the releases of Katumani synthetic I, Taboran, Katumani synthetic I and Katumani synthetic VI in 1960, 1961, 1963, and 1965, in that order.

Later, Katumani composite B was to be utilized as an important parental material for the medium potential maize breeding programmes of Central Kenya, based at Embu.

These varieties however still fell short of the requirements of some of the farmers especially in the drier areas of agroecological zones 4 and 5. For example, Rukandema *et al.* (1963) reported that about 70% of the farmers they interviewed in one location in the area did not grow the recommended and commercially available Katumani composite B. Efforts to form an earlier and more suited variety began in 1975 and the result has been a promising composite named Makueni.

Typical average yields and the times taken from sowing to flower by these various varieties are presented in Table 4. In the table, Katumani locality represents a drier than average environment while Maruba represents wetter than average locality. From the table, Makueni is clearly a very early maturing variety while Katumani composite B out yielded all the other varieties.

Current Maize Breeding Programme

Maize research programme in Kenya are technically co-ordinated by the Chief Research Officer resident at the National Agricultural Research Station at Kitale in Western Kenya. He is in-charge of convening an annual

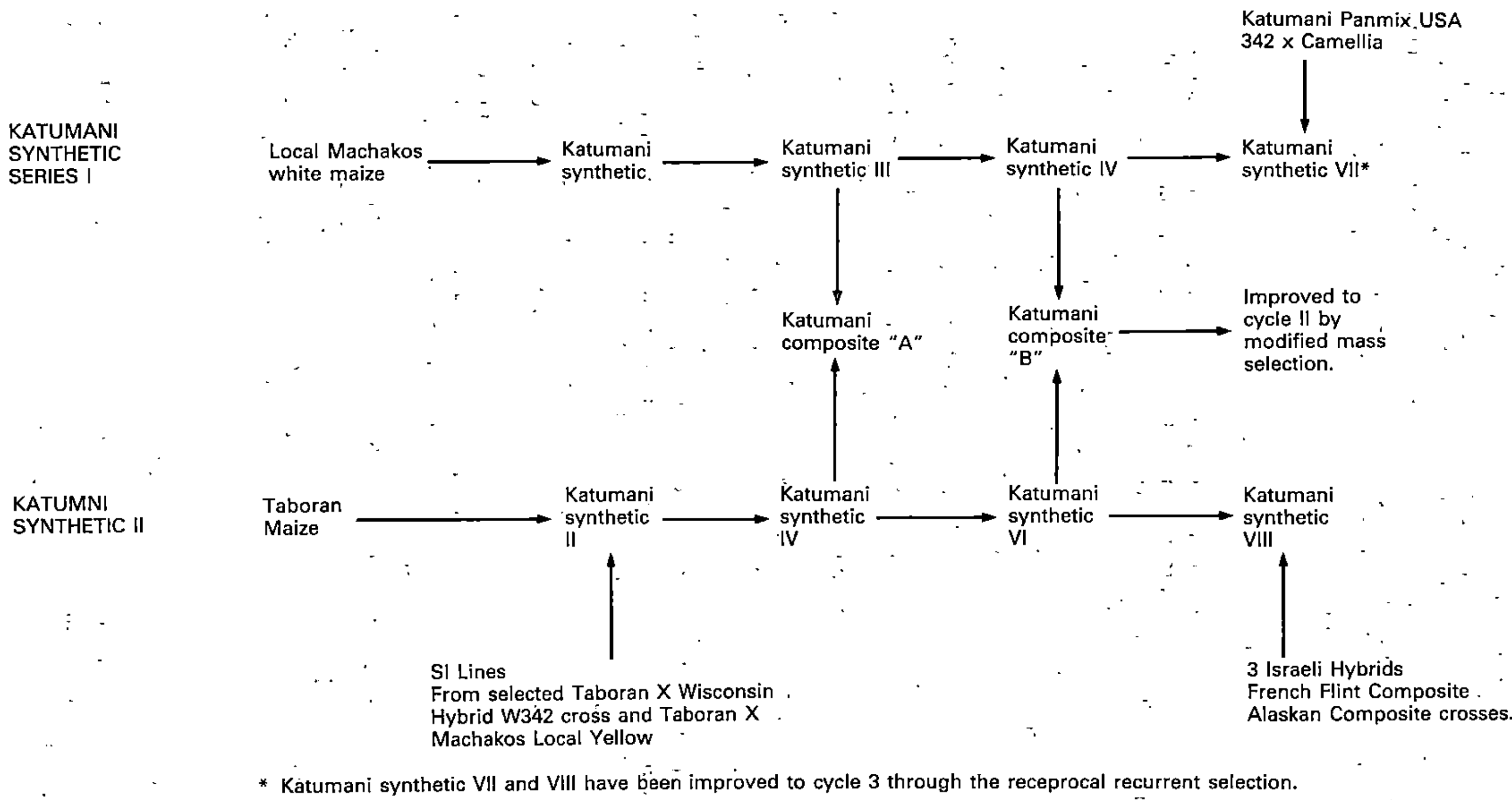

Figure 2 Schematic outline of the early maize breeding work at Katumani

Table 4 Mean days to flower and yields from thirteen Katumani maize varieties during 1983 short rains season

Variety	Katumani locality			Maruba locality		
	Yield (Q/Ha)	Silk emergence (days)	Pollen shed (days)	Yield (Q/Ha)	Silk emergence (days)	Pollen shed (days)
Katumani SYN I	8.44	68.0	64.0	23.05	66.0	64.5
Katumani SYN II	11.32	65.5	62	29.84	66.8	62.0
Katumani SYN III	17.08	67.0	60.0	29.64	64.5	60.0
Katumani SYN IV	13.32	63.3	60.5	32.21	63.8	60.5
Katumani Composite A	15.60	67.3	63.8	33.40	69.0	64.0
Katumani SYN V	15.64	68.0	62.2	28.40	65.3	60.5
Katumani SYN VI	8.44	65.8	61.8	20.17	66.3	61.0
Katumani Composite B	17.90	67.8	61.5	61.5	34.57	61.4
Katumani SYN VII	11.50	65.0	63.2	27.16	67.0	64.0
Katumani SYN VIII	12.55	63.0	59.3	28.40	64.8	60.5
Makueni Composite	16.80	59.0	55.0	20.58	59.3	55.25
Taboran	15.23	68.5	59.0	23.87	63.5	58.8
Machakos Local White	0.568	72.0	68.0	29.76	71.8	70.0
Mean	12.66	65.8	61.6	27.8	65.8	61.7
LSD ($P \angle 0.05$)	3.5	4.6	3.2	10.9	4.1	2.8
C.V.	23.0	4.2	3.9	24.0	4.6	2.8

Source From Njoroge (1982)

maize research specialist committee whose mandate includes initiating and winding up of all maize research programmes under the Ministry of Agriculture and Livestock Development.

The ongoing maize breeding programmes at Katumani still have the original objectives of developing adapted varieties of maize which have stable yields and which are, therefore, adapted to soil-water vagaries that are always crucial to farm productivity in the semi-arid areas. Improvement of populations through recurrent selection procedures remains the main activity. Makueni and Katumani composite B are being advanced through modified ear-to-row method while Katumani synthetic VII and Katumani synthetic VIII are being improved through reciprocal recurrent selection described by Eberhart (1966). Both Makueni composite and a cross between Katumani synthetic VII and Katumani synthetic VIII have been performing remarkably well in field trials and have now reached the final pre-release testing stages.

A prominent programme involves collection and evaluation of both local and foreign germplasm. Foreign germplasm is mainly introduced through collaboration with international bodies especially CIMMYT and SAFGRAD/IITA. Materials introduced from these centres commonly have characteristic wide variation in their yields both between seasons and across localities. They are also prone to disease attacks especially blight (*Helminthosporium turcium*) and rust (*Puccinia sorghi*). They flower generally later than local checks although occasionally some entries give considerably high yields probably indicating good potential. The following ten materials from these organisations have a tendency to give high yields at Katumani.

i. Tlatizapan 7845
ii. Sanjeranimo (i) 7941
iii. Michoacan 21 white (selection)
iv. Tlatizapan 7941
v. A selection from Pool 16
vi. Pirsabak (1) 7930
vii. Temp x Trop. No. 42
viii. Safita – 2
ix. Pool 34 QPM
x. BV 8330 SR

These materials are being incorporated in our breeding materials.

Seed Maize Production for the Semi-arid Areas

Katumani composite B maize, popularly known by the Kenya farmers simply as "Katumani maize" is perhaps the most versatile of all maize genotypes developed in Kenya. Though cultivated mainly in the Eastern Province, the variety is also widely grown throughout the semi-arid areas of Kenya. The cultivar has been exported to various countries of East and Central Africa. Seed production for the area is generally not a feasible commercial venture, although a viable seed production strategy devised to make improved seed available to and affordable by the producers in these areas is essential if a breeding programme is to be useful to the farmers.

Kenya has an efficient seed company, Kenya Seed Company, which has met the increasing demand for improved seed effectively. The company has acted as a vital research–farmer link in the production, processing, packaging and marketing of improved seed including hybrid seed maize from the hybrid programmes for the high potential areas. The company's sales from Katumani composite B maize seed has been extremely low when compared with hybrid-seed sales. (Table 5.)

Table 5 Maize seed sales in Kenya, 1981-1985 (figures in million kilogrammes)

Year	Katumani Composite B	Total seed maize
1981	0.5	30.2
1982	0.2	27.7
1983	0.5	32.2
1984	1.2	41.6
1985	1.1	41.3

Source: Kenya Seed Company Ltd.

The table shows that over the last five years Katumani composite B, the only commercially available maize for the semi-arid areas in Kenya, seed sales comprised only about two per cent of the Kenya Seed Company's total sales.

Improved seed would probably face the same problem of low sales aggravated by unpredictable demands. Additionally, the seeds may be sold at a very low retail price so that the target farmers can afford it. (Katumani composite B seed production is heavily subsidized). Unpredictable demands become a particularly serious problem during a season following a specially severe drought as occured in 1984. For example, during a normal year in Machakos District 20% of the farmers purchased planting material but during the season following the 1984 drought this percentage increased three fold (Muhammed et al 1985).

Future Breeding Work at Katumani

Maize breeding programmes at Katumani are expected to concentrate mainly on population improvement. The escape mechanism that has aimed at shortening the life-span of the crop has been achieved to within sufficient limits in most of our breeding materials and which are believed to have a high yield potential. In relation to yield, little progress is anticipated by further cutting maturity duration. Evidence indicates enhancing earliness further could mean compromising high yields below unacceptable levels. As Rosenow and Clark (1982) have cautioned, early maturing genotypes generally have negative relationships with yields. Efforts to reduce maturity will therefore be directed mainly at the incoming collections that may not be so adapted. In attempting to improve stable yields in the early maturing populations, emphasis will be placed on improvement of tolerance and drought resistance. Particular emphasis will also be placed on studies to understand the physiological and genetical basis of factors which control flowering behaviour.

Conclusion

A new challenge will emerge within the next few years from an anticipated mass movement of people into the fragile arable lands of zones 4 and 5, and may be to areas hitherto sparsely inhabited and considered too dry for maize cultivation. This new generation of farmers, displaced by the rapid expansion which characterises the Kenyan population, will continue to cultivate maize as their most preferred cereal. In these new environments, the climatic conditions will be different from the currently farmed semi-arid areas. Rainfall distribution will for instance be monomodal over most of these places.

A multidisciplinary approach to the development of new farming technologies will most likely gain prominence during this next phase. In designing future breeding programmes at Katumani, for example, the response farming concept developed by Stewart (1982, 1983) will be used. Observations will be made on both the timing of the onset of rainy seasons and the quantity of rainfall received early in such seasons to predict the final seasonal outcome of rainfall totals and concomitant crop yields. If a technique to foretell poor seasons could be identified early in the season, this could afford faster development of adapted maize varieties.

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19 La Production et la Sélection du Maïs dans les Pays du Sahel

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Introduction

Le CILSS est constitué de 8 Etats: Burkina Faso, Cap Vert, Gambie, Mali, Mauritanie, Niger, Sénégal et le Tchad. Les Etats faisant partie du Sahel avaient senti la nécessité de créer en 1973 le CILSS (Comité Inter Etats de Lutte contre la Sècheresse au Sahel) afin d'unir leurs efforts pour lutter contre la sècheresse, le sous développement et d'atteindre ainsi l'autosuffisance alimentaire.

Une première stratégie a été bâtie en 1977 par un groupe de travail ad hoc constitué par des experts de toutes nationalités. Elle a été adoptée par le Conseil des Ministres du CILSS en avril 1977.

Au moment des indépendances dans les années 60, il y avait environ 16 millions de sahéliens, en 1984 ils représentaient 35 millions de personnes. A part le Cap Vert actuellement il n'y a pas de baisse de la croissance démographique au niveau des autres pays.

Les céréales sont la base alimentaire de la grande majorité des populations du sahel et leur production dépend des conditions climatiques essentiellement. Ce que l'on constate c'est que la production diminue aussi bien en qualité qu'en quantité et que les besoins des pays ne sont pas couverts:

– en partant des tendances constatées depuis 25 ans, le sahel devra trouver au début du 21è siècle 3 à 4 millions de tonnes de céréales sur les marchés internationaux. Actuellement chaque producteur nourrit 3 consommateurs.

D'autre part, les pays sahéliens sont confrontés à une forte croissance démographique, un exode rural important, un élevage stagnant et subissant les conséquences de la sècheresse des terres qui se dégradent, une déforestation galopante, une situation économique et financière préoccupante et une dégradation des termes de l'échange. La dette de l'ensemble des pays du sahel est estimée en 1985 à 6 milliards de dollars. Malgré les efforts fournis par les sahéliens et l'aide internationale, malgré les stratégies d'Ottawa et de Koweit, la situation du sahel s'est dégradée. Il n'y a presque pas eu de progrès dans la voie de l'autosuffisance alimentaire.

Les besoins importants ressentis par les pays du sahel peuvent pourtant être couverts par les potentialités que recèle la région car des études ont montré que aussi bien les terres que les ressources en eau existent et que les possibilités d'accroitre les rendements sont considérables donc d'arriver à nourrir toute la population sahelienne durant le 3è millénaire.

Mais pour arriver à utiliser les potentialités, il faudrait des préalables: rétablissement des économies dont l'agriculture est le principal support, meilleure gestion de l'espace rural.

Caractéristiques Pedo-Climatiques des Pays du Sahel

Les potentialités agricoles dépendent beaucoup des vocations et aptitudes culturales qui varient elles-mêmes considérablement en Afrique au Sud du Sahara en fonction des grandes caractéristiques du milieu physique et naturel:

Le Relief

Dans les pays du sahel, le modèle du pays est caractérisé par un relief plat peu accidenté où emergent des plateaux peu élevés et des bassins.

Le Sol

D'une manière générale, les principaux types de sols que l'on trouve au sahel sont:

- des sols ferrugineux tropicaux non lessivés
- des sols ferrugineux tropicaux lessivés de texture limoneux-sableuse
- des sols hydromorphes mineraux lessivés de texture argilo-sableuse
- des sols ferralitiques erodés
- des sols sableux.

Ces sols présentent des caractéristiques communes importantes du point de vue agronomique.

• Leur texture est habituellement sableuse ou sablo argileuse dans les horizons superficiels et il y a une nette prédominance de la kaolinite dans la partie argileuse du sol.

• Du point de vue chimique ces sols sont assez pauvres: faible capacité d'échange, taux de matière organique et d'azote assez bas, taux de saturation du complexe absorbant de 40 à 100%, PH faiblement à franchement acide, carences chimiques fréquentes.

• Les phénomènes de lessivage sont importants du fait du caractère drainant des sols et des pertes minérales consécutives.

• La vie microbienne est très ralentie en saison sèche et accelerée en saison des pluies ce qui entraine une minéralisation intensive et rapide de l'azote.

• L'érosité assez forte est plus due à une très trande agressivité des pluies qu'à une forte susceptibilité des sols, ce qui implique une couverture du sol et des dispositifs anti-érosifs.

Le Climat

La zone de rencontre de la masse sèche tropicale avec la masse équatoriale humide et la zone de convergence intertropicale qui est une zone de perturbation ascendantes dont le passage au dessus des régions intertropicales Africaines apporte des pluies.

Durant la saison sèche la zone de convergence intertropicale varie de 6 à 9 mois et c'est l'harmattan qui est présent. Cette saison est caractérisée par la présence presque permanente de brume sèche.

Les périodes intersaisonnières se caractérisent par des passages nuageux accompagnés: d'averses brutales et d'orages sporadiques.

Dans les pays du sahel, la distribution des pluies est unimodale et il y a une grande variation pluviométrique due à la transition du sud au nord:

- d'un climat de type savane située dans la zone Nord-Guinéenne à pluviométrie comprise entre 900 et 1200 mm
- d'un climat de type sahelien correspondant à la zone sahélo-soudanienne (600 â 900 mm) dont l'ensoleillement est très elevé tout au long de l'année et des variations d'humidité considérables. Ce climat est caractérisé par:
  - une alternance très tranchée de deux saisons: sèche et pluvieuse
  - une possibilité photosynthétique exceptionnelle
  - un déficit hydrique chronique, plus ou moins accentué suivant les zones et saisons (absolu en saison sèche, irrégulier en saison des pluies)
- d'un climat sahélien (100 à 600 mm)
- d'un climat désertique.

La durée de la saison des pluies comme la pluviométrie annuelle moyenne dépend dans une grande mesure de la position latitudinale de la localité.

L'agriculture en Afrique

La mise en valeur agricole des régions tropicales d'Afrique a procédé à un schéma que l'on peut résumer en 3 points:

1) une phase qu'on peut appeler d'agriculture de subsistance qui est essentiellement orientée vers la satisfaction des besoins primaires particulièrement alimentaires. C'est une agriculture itinérante car la contrainte terre n'existe pas, le capital n'existe pas, le travail n'est pas rationalisé et la finalité de cette agriculture est l'autoconsommation.

2) la deuxième phase est caractérisée par l'accession à l'économie de marché par l'introduction de cultures d'exportation et industrielles qui a bouleversé les systèmes traditonnels qui sont alors remplacés par d'autres systèmes agricoles qui appauvrissent d'une manière plus ou moins rapide les sols. On pratique une certaine mécanisation légère favorisant une agriculture extensive. C'est la forme d'agriculture itinérante. La contrainte terre apparaît en même temps que sa fertilité naturelle diminue.

Le profit a comme corollaire dans ce cas la dégradation du capital foncier.

3) une phase d'intensification timide visant à une meilleure expression des potentialités naturelles, impliquant donc une conservation et une amélioration du capital foncier. On cherche à améliorer les systèmes de production non plus pour la production intrinsèque mais également pour atteindre aussi un développement harmonieux des différentes situations agronomiques et socio économiques. C'est en somme l'agriculture permanente supposant donc des exportations avec des structures et une organisation plus élaborées et des systèmes de production plus intensifs.

Ce schéma d'évolution de l'agriculture n'est pas appliqué dans la réalité car il n'y a pas cette succession dans les 3 types d'agriculture qui selon la logique devrait caractériser toute agriculture moderne; mais ce que l'on trouve souvent au niveau des pays, des régions ou des exploitations c'est une coexistence de ces 3 formes d'agriculture.

On doit toutefois souligner le caractère schématique de cette typologie des agricultures possibles, mais en fait ce que l'on trouve c'est l'existence même de nombreux types intermédiaires qui pourraient assurer une liaison progressive entre les types extrêmes.

La production céréalière au sahel

Les paysans dans les pays du sahel ont une superficie par personne assez faible; elle varie de 0,1 ha (Cap Vert) à 3,2 ha (Niger). La majorité des céréales cultivées et consommées dans les pays du sahel est constituée par du mil, du sorgho et du maïs. Le mil est la culture dominante au niveau de la Mauritanie et du Tchad (91% chacun), du Sénégal (81%) du Mali (70%) et du Niger (65%). Le sorgho occupe la première position au Burkina Faso (59%).

Tous les pays membres du CILSS sont importateurs de céréales, car la production et le rendement par ha des céréales sont très taibles à cause de la pratique d'une agriculture extensive, des sols pauvres et des conditions climatiques incertaines.

Pays	Population (millions) 1979	Taux de croissance population par an	Population agricole en 1977 %	Superficie cult. en céréales (mill. ha) 1975-77	Céréales cons. par habitant (kg/an) 1975-77	Importation de céréales cons. en % 1975-77
Burkina Faso	6,7	2,6	83	2,2	186	2
Cap Vert	0,3	1,8	58	0,1	131	90
Gambie	0,6	2,4	79	0,1	198	28
Mali	6,5	2,7	88	1,5	203	6
Mauritanie	1,6	2,8	84	0,2	135	69
Niger	5,1	2,9	90	2,9	271	3
Sénégal	5,5	2,6	76	1,1	210	28
Tchad	4,4	2,3	86	1,1	145	3

Source. Banque Mondiale, FAO, Conseil International pour le développement (UK) et publications Gouvernementales.

Le maïs

L'espèce Zea Mays L est une monocotylédone appartenant à la famille des graminées, tribu des Maydea ou tripsaceae. Zea Mays L est reliée à certaines espèces d'Andropogonade d'Amérique. La tribu Maydeae est divisée en 2 groupes géographiquement isolés:

- Les Maydeae Americains (Zea Mays L, Tripsacum L, Euchlaena Schrad)
- Les Maydeae Orientaux (Coix L, Polytoca R. Br, Sclerachne R Bv etc. . .)

Le maïs qui est une plante allogame et monoïque est cultivé du niveau de la mer à 4000 m d'altitude et de l'équateur aux latitudes 52° et sous divers climats depuis les régions chaudes à hautes ou petites pluviométries de l'Afrique aux contrées froides de l'URSS et du Canada. Le cycle varie de 68-70 jours pour une variété Russe à 16 mois pour une variété colombienne.

On pense que le maïs a été introduit en Afrique Occidentale au 17è siècle par les Portugais et que sa culture en Afrique de l'Ouest dans la zone à pluviométrie unimodale (climat Soudano-Guineen) provient des Caraïbes et de la vallée du Nil via l'Europe pour le type Flint (J.L. MARCHAND). Le maïs cultivé dans la zone sud-équatoriale à deux saisons de pluie proviendrait du Brésil.

Le maïs pousse bien sur des terrains aérés, riches en humus. Le maïs vient également bien sur la terre glaise et les terres argilo-sableuses.

La culture du maïs au sahel

Le maïs est cultivé par beaucoup de paysans mais sauf exception, les superficies consacrées à cette céréale ne sont pas importantes. Ceci se reflète sur les superficies cultivées en maïs par rapport aux superficies totales emblavées.

Dans les zones où la pluviométrie est inférieure à 1000 mm le maïs est souvent cultivé dans les terres riches c'est-à-dire les terres qui se trouvent autour des cases. Ce sont les autres céréales ou les cultures dites de rente qui occupent la majorité des terres de plein champ. Dans ce cas le maïs joue le rôle de culture de soudure à cause de son semis et de sa maturité précoces. Il commence à être une culture de rente quand le paysan s'éloigne un peu des concessions et dans ce cas il est cultivé sur des superficies plus importantes et souvent en agriculture semi-intensive ou intensive en rotation avec des cultures industrielles (arachide, coton, etc.). Il est également cultivé en association avec des céréales ou des légumineuses. La principale céréale qui entre en compétition avec le maïs est le sorgho qui est cultivé pratiquement sur les mêmes types de sols et sous la même pluviométrie. Le maïs pourrait prendre de l'extension si des variétés à haut potentiel de rendement et tolérantes à la sècheresse étaient vulgarisées et des techniques culturales adaptées étaient mises en pratique au niveau des producteurs.

Les productions

Au Burkina Faso la superficie en maïs est de 100.000 ha environ avec une production de 75.000 T. Les 80% de cette production sont obtenus dans la région Sud-Ouest c'est-à-dire dans la zone des 900 mm. Les rendements sont variables suivant que le maïs est associé au mil ou au sorgho (800 à 1500 kg/ha) ou en culture pure intensifiée (2000 à 3000 kg/ha). Les besoins du pays sont estimés à 110.000 T environ.

Le maïs a actuellement tendance à remplacer le sorgho aussi bien dans les spéculations culturales que dans l'alimentation.

Au Cap Vert, il est difficile d'estimer la production car elle est variable d'une année à l'autre à cause des facteurs climatiques défavorables qui sévissent dans le pays. Les surfaces emblavées sont de 35.000 ha, mais en association avec des haricots divers, soit 90% des terres en culture pluviale. Les rendements varient de 0 à 0700-750 kg/ha avec un maximum d'1T/ha dans les meilleures conditions. La moyenne des productions depuis 1970 est de 3 126 T. Les besoins sont estimés à 48 000 T de maïs, seulement environ 20% de ces besoins sont couverts.

En Gambie, le maïs est surtout cultivé en pluvial dans les plateaux. La superficie consacrée au maïs est de 6 400 ha pour une production de 6 144 T, soit un rendement de 960 kg/ha.

Au Mali, il y a près de 150 000 ha qui sont emblavés chaque année pour la culture du maïs qui couvre aussi bien la zone sahélienne que la zone soudano-guinéenne. Ces superficies représentent 10% des surfaces cultivées et les rendements varient de 2 100 kg/ha avec la CMDT à 600–800 kg/ha avec les OZL, OHV, OVSTM. Au Mali, la majorité de la production de maïs est obtenue dans les meilleures terres et les alluvions de la vallée du Niger dans la région de Sikasso (zone des 1 000 mm). L'objectif au Mali est d'atteindre une production de 160 000 T. Sur l'ensemble du pays le rendement du maïs est passé de 883 kg/ha en 1981 à 678 kg en 1982. Cette région abrite également le coton et l'arachide. Dans presque la moitié du pays, il n'y a que le nomadisme qui est pratiqué à cause de l'aridité du milieu.

En Mauritanie le maïs est une plante très cultivée. De toutes les céréales, c'est lui qui vient en troisième position après le sorgho et le mil. Le maïs est cultivé sur le versant intérieur du fleuve Sénégal (culture de décrue et dans les périmètres irrigués) de même que dans les terres des bas-fonds. Le rendement moyen est de 600 kg/ha.

Au Niger le maïs se cultive en grande partie dans la vallée du GOUL-BI, dans la cuvette de KOLO, de KAWARA et BENGOU. En 1983/84 la production était de 6000 T.

Au Sénégal la culture de maïs est réalisée en majorité sous conditions pluviales à partir de l'isohyète 800 mm jusqu'à l'isohyète 1 500 mm c'est-à-dire au Sud du Sine Saloum, au Sénégal Oriental et en Casamance. Il existe une culture de maïs qui est pratiquée dans la vallée du fleuve. La production a presque triplé de 1970 à 1982 passant de 33 075 T à 82 148 T pour des superficies de 50 640 ha à 86 241 ha – En 1984 la production est estimée à 98 450 T pour une superficie de 82 680 ha.

Au Tchad, les statistiques de production de maïs indiquent 15 000 T pour 20 000 ha qui sont emblavés.

Les zones et systèmes de culture

Au Burkina Faso les différents systèmes de culture de maïs sont:

- Des cultures dites de case qui sont très répandues dans les zones sèches qui utilisent des variétés très précoces (70 jours). Ce sont des cultures pures et le maïs se succède à lui même. Cette culture se pratique dans les zones de plateaux et la région centrale ayant une pluviométrie de 600 à 850 mm.
- Des cultures de plein champ pratiquées dans le Sud du pays. Les cultures sont en association soit avec le mil ou le sorgho soit en culture pure quand c'est l'intensification qui est pratiquée (zone contonnière). Le maïs succède au coton bénéficiant de l'arrière effet de ce dernier. La culture se pratique dans les isohyètes 1000 mm et plus.
- Des cultures de bas-fonds ou au bas des pentes.
- Des cultures associées: igname sur défriche suivie de plusieurs années d'association maïs-mil (Sud-Ouest) – Dans les zones sans igname on retrouve l'association maïs-mil ou maïs-sorgho sur plusieurs années.
- Des cultures sous irrigation dans les vallées du Kou et du Sourou.

Les variétés utilisées sont précoces. La couleur du grain varie avec les régions de culture – Les variétés à grain blanc et jaune sont cultivées dans l'Ouest du pays – Le type de grain le plus répandu est le maïs semi corné à corné.

Comme variétés vulgarisées on trouve:

- Jaune Flint de Saria qui est cultivée dans la partie la plus septentrionale et la plus sèche de la zone maïsicole. Son cycle total est d'environ 80 jours et son potentiel de rendement de 3 500 kg/ha.
- IRAT 80 qui est une variété à grain jaune avec un cycle de 105 jours. Son potentiel de rendement est de 5 500 kg/ha. C'est un cultivar destiné aux zones à pluviométrie supérieure à 900 mm.
- Massayomba est une population locale à grain blanc avec un cycle de 100 jours; son potentiel de rendement est à 5 000 kg/ha. Elle est également vulgarisée dans les zones à pluviométrie supérieure à 900 mm.
- NCB blanc qui provient de NCB rb du Nigéria et qui porte actuellement

le nom de IRAT 171, il est vulgarisable dans la zone de l'opération cultures vivrières Ouest Volta. Il a un cycle de 100 jours et son rendement est supérieur de 12 à 19% à Massayomba.
- Jaune de Fo
- Des cultivars sont en prévulgarisaton: Maka au cycle inférieur à 95 jours et IRAT 200. Poza Rica 7822 compris entre 95 et 110 jours.
- Il y a des hybrides et variétés qui sont vulgarisables: IRAT 100 (à grain jaune et 100 jours de cycle), IRAT 102 (à grain blanc et 105 jours de cycle), IRAT 81 (à grain blanc crée en Côte d'Ivoire et à 115 jours de cycle), SAFITA 102 et 104 (crées par le SAFGRAD).

Au Cap-Vert, le maïs est l'alimentation de base, (cachupa) il est presque toujours en association avec les haricots divers (niébé, phaséolus lunatus, dolique, phaséolus vulgaris, pois cajan). La culture est du type traditionnel donc manuelle et utilise des populations locales dont la durée du cycle varie de 90 à 100 jours. Les maïs Cap-Verdiens ont subi une pression de sélection naturelle qui leur confère une bonne rusticité et une tolérance à la sècheresse. La couleur des grains varie du jaune corné au blanc avec des phénomènes de Xenie plus ou moins importants.

Les terres emblavées vont des plateaux avec des sols relativement profonds (achadas) à de fortes pentes souvent pièrreuses. La culture du maïs se pratique dans les îles Santiago, Fogo, Santa Antao et Sao Nicolau. Le maïs se cultive également en irrigué.

Les variétés cultivées sont:

- Population Maio originaire de l'île de Maio ayant un cycle de 90 jours et un grain jaune corné.
- Composite blanc Fogo, originaire de l'île de Fogo avec un cycle de 100-110 jours et un grain blanc corné.
- Population Santa Catarina originaire de l'île de Santiago avec un cycle de 100-110 jours et un grain jaune corné.

En Gambie, le maïs est une culture largement pratiquée en association avec le mil ou le sorgho dans la moitié Est du pays et il remplace le sorgho et le mil comme culture de soudure. Dans la moitié Ouest du pays, il est cultivé comme culture maraichère. Actuellement les paysans ont tendance à faire des cultures de plein champ pour augmenter la production car avec l'installation d'usines de transformation (aliments de volaille), le maïs a tendance à devenir une culture de rente. Avec les techniques recommandées, certains paysans arrivent à obtenir des rendements de 2 800 kg/ha.

Les variétés cultivées sont JEKA qui est une population locale et le composite NCB du Nigéria. Leur potentiel de rendement est compris entre 3 et 4 T/ha.

Au Mali il existe différentes zones de culture du maïs:

- Dans la zone où la pluviométrie est inférieure à 800 mm, la culture du maïs se pratique dans les bas-fonds, le bas des pentes, au bord des lacs et des rivières.
- Dans le sud et le centre du pays où la pluviométrie est supérieure á 1 000 mm et où intervient la Compagnie Malienne de Développement Textile (CMDT) la culture du maïs se fait en culture pure en assolement avec le coton et l'arachide. Il y a également le centre et l'ouest du pays. Chez les paysans encadrés par l'Opération Arachide et Cultures Vivrières (OACV) la culture du maïs est en intensif en culture pure.

- Dans la vallée du fleuve Sénégal et en bordure du lac Magui et de la rivière Kolombino (sur 2 000 ha), la culture du maïs se fait en décrue.
- Autour des cases, ce qui est pratiquement général dans tout le pays et qui représente l'essentiel de la production de maïs au Mali.

Dans la zone Méridionale c'est-à-dire la zone la plus pluvieuse, le maïs est presque toujours cultivé en association soit avec le mil soit avec le sorgho. Le maïs est également cultivé en association avec les légumineuses.

Ce sont les variétés précoces qui sont les plus cultivées.

- Tiemantié à grain jaune corné avec un cycle de 100 jours et un potentiel de 5 T/ha.
- Zanguerini à grain jaune corné également à un cycle de 90 jours et un potentiel de rendement de 3,5 T/ha.
- Kogoni B a aussi un grain jaune corné et un cycle de 85 jours et un potentiel de rendement de 3,5 T/ha.
- IRAT 85 qui est un composite Malo-Voltaïque.
- Massayomba à grain blanc et un cycle de 100 jours.

En Mauritanie la culture traditionnelle du maïs se fait aussi bien en hivernage qu'en saison sèche en culture de décrue et en association avec le niébé. Les semis se font à plat plutôt qu'en billons durant la saison sèche. La saison sèche froide reste la meilleure saison pour la culture du maïs dans la moyenne vallée. Il existe des potentialités énormes car avec les variétés améliorées les rendements peuvent atteindre 4 à 5 T/ha si le semis est effectué avant le début du mois de Novembre pour que la floraison échappe à l'arrivée de l'harmattan (vent chaud et sec).

On trouve le maïs dans différents endroits en Mauritanie:

- Dans les Oasis ce sont des zones où la nappe n'est pas profonde et est permanente. Il y a en Mauritanie 6 000 ha environ qui sont des oasis et qui permettent la culture sans l'influence de la pluie. Ce sont des endroits qui abritent les palmeraies mais des cultures vivrières y sont pratiquées et totalement autoconsommées.
- Les décrues: les terres de décrue couvrent 35 000 ha et sont situées sur les berges du fleuve Sénégal et de ses affluents. Ces cultures dépendent de la crue et se développent en saison sèche. Certaines cultures de bas-fonds entrent dans cette catégorie quand éles sont à côté de barrages ou de retenues.
- Les cultures sous pluie: elles sont situées dans les bas-fonds et sur les passages d'eau, elles bénéficient de l'apport complémentaire des eaux de pluie.
- En année favorable on estime les cultures sous pluie à 40–50 000 ha. – On retrouve cette culture dans les régions de Guidamaka (Selibaby).
- Le système pluvial strict: ce sont des cultures qui ne reçoivent que la pluviométrie tombée donc ce sont des cultures à haut risque. Les superficies pour ce genre de culture ne sont pas limitatives.
- Les systèmes irrigués: des périmètres irrigués sont actuellement aménagés et la culture du maïs se pratique en toute saison.

La variété la plus cultivée est la population locale améliorée MAKA. D'autres variétés comme Early Thaïs sont également cultivées. La variété locale MAKA demande un renouvellement des semences à cause de la sélection massale et de la promixité d'autres variétés en culture. Les paysans en consommant au stade vert les meilleurs épis de Maka font dégénérer le potentiel génétique de la variété au bout de quelques années.

Au Niger le maïs est beaucoup cultivé sous pluvial autour des concessions dans les zones où la pluviométrie est assez correcte. Le maïs est également cultivé dans les bas-fonds, autour des lacs et en décrue sur les berges du fleuve Niger – Actuellement dans les périmètres irrigués, le maïs devient une culture entrant dans l'assolement et une culture pure.

Le maïs est très consommé au Niger. Il n'y a pratiquement qu'une seule variété qui a été sélectionnée par l'IRAT et qui est P3 KOLO.

Au Sénégal la culture du maïs est pratiquée sous différentes conditions et prend de plus en plus de l'importance.

- Culture autour des cases pour l'autoconsommation sur des superficies généralement réduites. En Casamance cette forme de culture est souvent mise sur billons.
- Culture en plein champ et c'est cette dernière méthode de culture qui tend à se développer grâce à l'intervention des sociétés de développement qui préconisent des techniques culturales appropriées. Cette culture est pratiquée dans les zones pluviométriques de 800 à 1 200 mm et dans la vallée du fleuve sur les périmètres irrigués villageois. La culture dans certains cas est faite à plat suivie d'un buttage au 40è jour après le semis.
  - Dans les bas-fonds des zones où la pluviométrie est limitée
  - Sur la vallée du fleuve Sénégal la culture du maïs se fait en décrue quand la pluviométrie a permis la crue du fleuve Sénégal (falos). Cette culture se pratique pendant la saison sèche froide sur les faux Hollaldès fondes et weales. Dans la vallée du fleuve il y a également des périmètres irrigués villageois où la culture du maïs se fait sur billons ou à plat au longal. En hivernage avec une irrigation complémentaire on pratique la culture du maïs. Le maïs est aussi en rotation avec le riz ou le maïs.

Dans certaines zones notamment dans les hauts plateaux de la Casamance, le maïs a connu des augmentations de superficies d'environ 19% par an durant le 5è plan.

Plusieurs variétés sont actuellement cultivées ou en phase de vulgarisation.

- BDS III qui est un hybride complexe à grain blanc corné avec un cycle de 90 jours et un potentiel de rendement de 5 T/ha.
- AM10 est une population locale améliorée avec également un grain blanc corné et un cycle de 90 jours. Son potentiel est de 3-4 T/ha.
- Camara 1 est une variété à grain jaune denté ayant un cycle de 90 jours, résistante à la sècheresse et un potentiel de 4 T/ha.
- Synthétique C est une variété à grain blanc 1/2 corné avec un cycle de 90 jours, tolérante à la sècheresse et un potentiel de 4 T/ha.
- QPM1 est une variété opaque 2 sélectionnée en milieu paysan, à grain blanc semi denté avec un cycle de 90 jours et un potentiel de 3,5 T/ha.
- Maka est une population locale cultivée au niveau de la vallée du fleuve Sénégal, avec un potentiel de 3 T/ha. Il y a également d'autres variétés cultivées dans cette zone qui sont Early Thai, Penjalinan et Diara.

D'autres variétés sont en voie de vulgarisation: HVB-1, HVB-2 qui sont des hybrides variétaux, CP75 qui est un composite très précoce, un composite blanc denté et un composite jaune denté, QPM2.

Au Tchad le maïs qui est une culture de soudure tend à remplacer progressivement le riz, le sorgho et le mil dans certaines régions du pays.

En hivernage le maïs est cultivé soit en association avec le niébé, les cucurbit, acées, le gombo, l'oseille soit en culture pure dans la zone Sud du pays plus arrosée et où la culture du coton est bien développée.

La majorité des terres emblavées en maïs concerne la culture du maïs autour des cases dans la zone Sahélo-Soudanienne et surtout Nord-Guinéenne (900 à 1 200 mm).

On pratique également la culture pure du maïs en contre saison autour du lac Tchad, les rives des fleuves Chari et Logone, dans le Karal et Bol.

Les variétiés vulgarisées sont SMB, BDP, Pelinka. Elles ont des rendements qui font 2 T/ha en moyenne. Les variétés vulgarisées sont du cycle court ou intermédiaire. La couleur du grain varie selon les régions mais le maïs jaune est plus cultivé que le maïs blanc.

Parmi les essais internationaux des variétés ont été trouvées prometteuses: il s'agit de TZPB. Mexican 17 Early, IRAT 171 et CJB.

Les contraintes liées à la production

Contraintes au niveau de l'écologie

L'Eau.

La plupart de l'agriculture sahelienne est pluviale. C'est la pluie qui commande essentiellement les rendements et qui conditionne l'efficacité de l'input. Depuis plus d'une décennie, les pays du sahel vivent des conditions de sécheresse qui accentuent encore plus la désertification.

Depuis plus d'une décennie il apparaît un déficit chronique au niveau de la pluviométrie aggravé par une très mauvaise répartition des pluies. Ce phénomène est surtout marqué dans la zone Sahélo-Soudanienne. La zone Nord-Guinéenne bien que connaissant également des poches de sécheresse parait mieux lotie que toutes les zones à pluviométrie inférieure.

Les cours d'eau ne sont pas également nombreux ce qui limite les possibilités d'irrigation mais l'implantation des barrages pourrait améliorer cette situation. Il existe des potentialités hydriques dans le sous-sol qui sont faiblement exploitées.

La plus grande partie des pluies annuelles est reçue pendant une saison relativement courte communément appelée hivernage. Ces pluies sont variables et aléatoires ce qui diminue considérablement le potentiel agricole et augmente les besoins en eau des populations et des animaux.

Le Sol

La grande majorité des sols exondés du sahel rentrent dans la classification des sols ferrugineux tropicaux plus ou moins lessivés, des sols ferralitiques et des sols peu évolués sableux. Ils sont caractérisés par:

- une faible porosité
- une très forte cohésion du sol quand il est sec
- une teneur en matière organique, en phosphate, en azote et en oli-go-éléments faible
- des érosions plus ou moins sévères pendant la saison sèche et même l'hivernage
- un mauvais drainage

– une toxicité ferrique et aluminique et une acidification qui s'aggravent continuellement.

Les maladies et les ravageurs

Les principales maladies que l'on rencontre dans la zone sahélienne sont le streak virus, la rouille, l'helminthosporium curvilaria lunata, physioderma et quelques cas de pourriture de l'épi ou de la tige. Pour les ravageurs, les principaux sont les termites, les borers, les pucerons, les iules et les insectes au niveau du stockage.

Contraintes structurelles

Les structures agraires

En matière de terres, leur distribution obéit aux coutumes et usages traditionnels. Dans certains pays la précarité du droit d'usufruit est un obstacle à une mise en valeur du terroir. Les familles fondatrices des villages peuvent parfois exercer un droit exclusif sur les réserves foncières. Dans les pays où il y a une législation, elle est souvent entachée de pratiques locales.

Le mode d'exploitation

Le morcellement des propriétés en de nombreuses parcelles de superficie restreinte et de formes irrégulières est un obstacle à une utilisation rationnelle des moyens de production.

Contraintes techniques

Le dessouchage

C'est une opération pénible en saison sèche à cause de la prise en masse et le paysan n'a pas les moyens techniques d'y faire face. En saison humide le dessouchage est moins pénible car les sols sont humides mais il se pose le problème du calendrier de travail. Le dessouchage des terres est une des contraintes bloquant l'extension des surfaces en amélioration foncière.

Le matériel agricole

Le capital du petit paysan se résume généralement en du petit matériel manuel et de l'équipement pour le semis et le sarclage. L'utilisation de la traction animale est très limitée dans certains pays et pour réaliser le labour, l'agriculteur doit posséder au moins une paire de boeufs et une charrue. Pour une intensification de la culture du maïs, ill faut nécessairement l'acquisition de matériels nouveaux plus performants (polyculture ariana charrue, charrette etc.). Le matériel servant pour les traitements post récolte est extrêmement faible.

Le labour

Les céréales sont très sensibles aux effets du labour qui vont en augmentant lorsqu'on passe du mil au sorgho puis au maïs et au riz pluvial. Si le sol est dégradé, le labour accompagné d'enfouissement de matière organique est un bon moyen d'augmenter les rendements et la fertilité des sols. Les contraintes qui se posent à ce thème sont:

- il existe des problèmes d'équipement comme souligné plus haut, car pour labourer il faut au moins une paire de boeufs et le matériel tracté.
- les parcelles morcellées ne facilitent pas l'opération du labour.
- il y a des contraintes techniques de réalisation (technicité du paysan et calendrier de réalisation)
- le cycle de la plante, nécessité de caler le cycle avec la durée de l'hivernage
- nécessité de protéger les zones labourées.

Les semences

Les semences de base produites par la Recherche sont caractérisées par leur bon état sanitaire, leur pureté variétale et leur bonne faculté germinative. Il faudrait une bonne organisation des services nationaux pour maintenir ces caractéristiques et mettre les semences à la disposition des paysans à temps. Les variétés à haut potentiel de rendement et bien adaptées font défaut dans certains pays qui ne cultivent que des populations locales en majorité.

Le semis

Ce thème est étroitement lié aux préparations du sol et à la pluviométrie. Le maïs devant être semé après les premières pluies voit son semis souvent différé à cause du manque de matériel agricole, de main d'oeuvre etc. Les semis tardifs et les démariages trop tardifs, un mauvais contrôle des adventices sont autant de facteurs qui agissent négativement sur les rendements.

Les fumures

Les problèmes rencontrés par les paysans sont:

- les quantités disponibles sont insuffisantes car il y a des problèmes d'importation ou de production
- le nombre de points de vente n'est pas suffisant
- la mise en place est souvent tardive
- risque d'augmentation du prix des engrais même s'il est subventionné ce qui grèvera encore plus le budget du paysan.

L'entretien des cultures

Il est fortement lié au calendrier cultural, au degré d'équipement et à la qualité de la main d'oeuvre. Les paysans sous équipés n'ont pas le temps de faire tous les sarclages nécessaires à l'entretien de la culture car les mauvaises herbes constituent une importante contrainte. Dans certains pays la striga cause beaucoup de dommages.

Les rotations

Les contraintes de rotations sont assez importantes en céréaliculture car le chef d'exploitation ne produit que ce qu'il faut pour sa consommation.

Contraintes socio-économiques

Généralement la situation financière des agriculteurs, surtout chez les exploitants secondaires est peu brillante. Mise à part l'épargne constituée par le bétail, l'argent et même les excédents de céréales disparaissent rapidement après la récolte et l'usure est une pratique courante. L'épargne est quasiment nulle à cause de leurs faibles revenus.

Le stockage

Les pertes subies après récolte sont fort élevées lorsque des moyens corrects pour le stockage font défaut comme cela arrive souvent au niveau des petites exploitations rurales. Les épis entreposés ne subissent en général aucun traitement phytosanitaire. Le maïs est séché à même le sol avant son entreposage, ce qui occasionne des attaques d'insectes et d'oiseaux.

La commercialisation

Le paysan produit surtout et avant tout pour couvrir les besoins alimentaires de sa famille et ne vend que les surplus. Pour avoir de l'argent il s'adonne aux cultures de rente dont les prix sont plus rémunérateurs. L'organisation efficace de la commercialisation est une des conditions essentielles pour la promotion de la culture de maïs. Le prix au producteur s'il est intéressant pourrait inciter l'agriculteur à produire plus, donc à accroître ses revenus.

Les solutions aux différentes contraintes

L'Eau

Il suffira d'adopter une politique d'économie de l'eau. Une maîtrise de l'eau imparfaite augmente les difficultés d'exploitation et réduit la productivité. Cette politique d'économie de l'eau devra être basée sur la création de variétés tolérantes à la sécheresse et l'amélioration des conditions d'alimentation hydrique par un aménagement du système sol-eau. Il faudra également réduire les pertes d'eau par ruissellement, évaporation et la consommation par les mauvaises herbes et assurer une bonne utilisation par la plante de l'eau stockée dans le sol grâce à un système racinaire vigoureux.

Le sol

Le retournement du sol par la charrue, permet d'avoir un effet immédiat et d'augmenter la porosité du sol et sa rugosité, ce qui favorise l'infiltration de l'eau au moment des premières pluies ainsi que la pénétration et l'extension des racines. Le conditionnement du sol par la charrue permet également d'enfouir la matière organique et les engrais, ce qui entraîne une réduction des pertes d'azote, une meilleure répartition des racines et une meilleure efficacité de l'engrais en cas de sécheresse et une augmentation de la teneur en matière organique du sol si on fait de l'enfouissement. La plantation de brise vent et un meilleur aménagement du sol diminueraient l'érosion. L'apport de matière organique et d'amendement calcique serait la solution contre l'acidification.

Les maladies et ravageurs

Il faut créer des variétés résistantes aux différentes maladies et ravageurs. L'autre forme de lutte contre les insectes et les champignons est l'utilisation de traitements chimiques, d'appat. Les techniques culturales peuvent également constituer un moyen de lutte contre les ravageurs et les maladies.

Les structures agraires

Le projet de régime foncier par le bornage des champs peut résoudre la contrainte du droit foncier lorsque l'appartenance des terres est définitivement fixée. Une meilleure règlementation devrait aider les paysans à mieux comprendre la législation si elle existe et éviter des conflits.

Le mode d'exploitation

Le regroupement en parcelles de formes régulières et de grande dimension est nécessaire par le biais du remembrement qui permet:

- de limiter les parcelles et donc d'éviter les litiges à propos du droit foncier
- une meilleure adaptation des parcelles à la traction bovine et à l'introduction de matériels lourds
- de connaître les superficies cultivées donc de prévoir la quantité de facteurs de production nécessaires
- de faciliter le travail d'encadrement et la collaboration entre le chef d'exploitation et ses travailleurs.

Le remembrement est également rendu indispensable à cause des problèmes de conservation des sols, d'aménagement des zones de parcours et de lutte contre l'érosion.

Le dessouchage

Il faudrait mettre en place un crédit dessouchage qui sera un prêt de campagne remboursable sans intérêt au moment de la commercialisation. D'autre part, le rythme de dessouchage sera compatible avec la progression de reboisement (brise vent, haies vives, etc. . .) on cherchera à compenser la disparition des arbres et arbustes victimes du dessouchage mais aussi à assurer à la fois la délimitation des grandes parcelles de culture et la lutte contre l'érosion éolienne (brise vent) et hydrique (ruissellement).

Le dessouchage permet d'améliorer les conditions de travail du sol, de passage des outils et du labour.

Le matériel agricole

Les améliorations apportées au matériel, y compris les instruments aratoires à traction animale et les outils manuels aussi bien que les tracteurs et le matériel à traction mécanique peuvent contribuer considérablement à élever le rendement à l'ha, d'abord parce qu'elles permettent de mieux accomplir diverses opérations et ensuite parce qu'elles permettent de faire les travaux en temps opportun. Une politique volontariste d'équipement en matière agricole au niveau des paysans doit être entreprise au niveau des pays pour rationaliser un peu la production.

Le labour

Sur sols faiblement ferralitiques, les résultats de travail du sol sont comparables à ceux obtenus sur les sols ferrugineux tropicaux. Si le sol est dégradé, le labour accompagné d'enfouissement est un moyen d'augmenter les rendements et d'améliorer la fertilité. De nombreux suivis de profils hydriques effectués pendant des périodes de sècheresse en cours de culture, ont permis de vérifier que les plantes cultivées sur labour explorent plus complètement les réserves hydriques du sol. Le labour peut avoir des effets résiduels non négligeables pendant plusieurs années.

Le type de labour le plus conseillé dans la zone sahélienne est le labour de fin de cycle et le labour en sec à condition d'effectuer d'abord un desherbage mécanique juste après la récolte pour maintenir une certaine humidité afin d'empêcher la prise en masse du sol.

Le buttage a aussi un effet significatif sur la culture du maïs, il permet:

- de diminuer la verse en cas de vents forts
- de lutter efficacement contre les adventices
- d'éviter le phénomène d'asphyxie hydrique sur des sols qui ne drainent pas bien.

Le billonnage cloisonné ou non permet de maintenir une certaine humidité du sol, c'est donc un des moyens de lutte contre la sécheresse.

Les semences

Il faut mettre à la disposition des paysans des variétés améliorées selon leur degré de technologie. Une bonne organisation des services de recherches et des services semenciers nationaux devrait conduire à une meilleure utilisation des semences sélectionnées. Il faudrait également:

- améliorer les prévisions en besoins de semence de base par un système d'enquêtes
- créer des fermes semencières
- élaborer un catalogue de variétés officielles.

Les semences utilisées doivent être de qualité et appartenir aux variétés les mieux adaptées et les plus productives pour la zone concernée. Elles doivent avoir de bonnes qualités technologiques et organoleptiques. Du point de vue génotype les cultivars devraient avoir une bonne résistance à la sécheresse et aux maladies.

Les semis

Il n'est pas conseillé de semer le maïs à sec. Certains paysans le font mais des risques de pourriture des graines existent si le sol n'est pas suffisamment humidifié car le maïs a besoin d'assez d'humidité pour germer dans de bonnes conditions. Il n'est pas également conseillé de semer dans les périodes de fortes averses, car le maïs craint également l'excès d'eau. Il faut semer en temps optimum si possible car des études ont montré que des différences significatives de rendement sont obtenues selon les dates et modes de semis.

Grâce à l'utilisation de la traction bovine et d'un matériel adapté au mode de traction, il est possible de supprimer les goulots d'étranglement qui apparaissent au moment des semis et sarclages.

Du point de vue densité, d'une manière générale on peut considérer qu'une bonne densité de semis est comprise entre 40.000 et 60.000 pieds/ha. On peut cependant noter que:

- les cultivars à paille courte ou à cycle précoce supportent des densités plus élevées que ceux à paille haute et à cycle long.
- l'irrigation d'appoint ne permet toujours pas d'augmenter la densité à moins que la variété soit résistance à la verse et qu'elle puisse supporter des densités fortes.
- à un niveau de fertilité faible, une densité faible est préférable.

Les fumures

L'utilisation des fumures fortes permet de maintenir ou d'ameliorer la fertilité des sols pour compenser les exportations faites par les récoltes. En fonction des rendements escomptables en année moyenne, les fumures d'entretien sont calculées de manière à combler les exportations par les récoltes et même laisser un bilan légèrement positif.

Pour promouvoir l'extension à l'utilisation des engrais il faut:

- en produire ou en importer suffisamment
- les mettre en place assez tôt tout en augmentant les points de vente pour les rendre plus accessibles.
- subventionner l'engrais pour populariser sa consommation.

L'utilisation de fumure organique est également souhaitable pour améliorer la fertilité des sols.

L'entretien des cultures

Pour éviter les goulots d'étranglement au niveau des sarclo-binages, il faudrait accélerer le niveau d'équipement des exploitations agricoles en matériels et moyens de traction.

En ce qui concerne le sarclage il est conseillé de le faire 10 jours après la levée si des herbicides n'ont pas été utilisés. Un ou deux entretiens à plat sont généralement nécessaires avant le buttage qui est réalisé 30 à 40 jours après le semis.

Les rotations

D'une manière générale le maïs entre bien en rotation avec le cotonnier, l'arachide et le niébé. En sols sableux ou dégradés les successions céréales sur céréales sont déconseillées, il est préférable de respecter l'alternance céréale-légumineuse. Dès que la teneur en argile augmente, on peut dans certaines conditions envisager des successions avec le mil ou une culture continue maïs-maïs. En sol très argileux toutes les combinaisons sont possibles à condition de ne pas les placer derrière une jachère ou défriche.

Socio-économie

La diminution de la pénibilité du travail grâce à la mécanisation et à la motorisation et l'élévation des revenus constituent des incitations favorables pour surmonter certains problèmes.

Pour l'expression des potentialités d'une exploitation, l'homme devra apporter son travail, son adresse, sa technicité et les intrants nécessaires pour que chaque morceau de terre soit utilisé pour ce qu'il est capable de produire le plus efficacement. Pour atteindre cet objectif il faudra non seulement lui donner les moyens mais également le former pour qu'il puisse maîtriser les techniques modernes. Le blocage initial dans l'admission des innovations peut être levé partiellement par l'appui technique de l'encadrement et le climat de confiance qui doit règner entre paysans et encadreurs.

Toutes les innovations seront diffusées simultanément dans le cadre d'u sysème permettant une meilleure efficacité des nouvelles techniques proposées et une évolution plus rationnelle de l'exploitation. Cette diffusion s'adressera en premier lieu aux paysans les plus influents et ouverts aux progrès.

L'agriculture à part sa fonction première de nourrir les hommes doit également constituer une source de revenus pour celui qui la pratique.

Le stockage

Si on veut avoir un bon stockage en épi du maïs l'utilisation de cribs constitue le moyen comportant le moins de risques de perte. Le stockage dans les cuisines ne semble pas être également une mauvaise solution.

Si au niveau du village, le stockage doit se faire en grain, l'utilisation de magasins à cellules ou de fûts de 200 l expérimentés au Sénégal permet une bonne conservation des grains en vrac.

La commercialisation

L'organisation rationnelle de la commercialisation est une des conditions essentielles à la promotion des productions céréalières particulièrement du maïs auprès des paysans. Tant que le producteur n'aura pas perçu des débouchés sûrs et une source de revenu garanti pour sa culture, il s'en tiendra toujours à produire strictement pour son autoconsommation. Pour être attractive la commercialisation du maïs doit se situer peu après la récolte, longtemps avant celle de la culture de rente; à cette époque les revenus des paysans sont faibles ou nuls pour nombre d'entre eux. Une meilleure organisation de la commercialisation doit être mise en place, ce qui nécessite:

- l'étude du marché et des circuits
- l'étude du prix au producteur

Il faudra mettre en place une politique d'extension du marché intérieur par le biais des transformations industrielles et tenter de s'ouvrir également vers l'exportation.

Les programmes de recherche

Un effort a été fait depuis quelques années pour doter les pays du CILSS non seulement d'Instituts de Recherches mais également dans le cas particulier du maïs de programmes de recherches qui sont assez étoffés dans certains pays mais pour d'autres l'essentiel est constitué de tests variétaux pour pouvoir sélectionner des variétés adaptées aux conditions écologiques propres au pays. C'est ainsi que:

Au Burkina Faso il y a d'importants programmes de recherches qui sont menés essentiellement par le SAFGRAD et l'IRAT.

Au niveau du SAFGRAD les recherches portent sur:

- la sélection pour la précocité et le rendement en grain. C'est la sélection recurrente multi-locale (MLRS: Multilocation Recurrent Sélection)
- sélection au sein de 8 populations précoces
- croisement de populations précoces (pool 16, TZB4) et intermédiaires (TZPB et TZSR) et sélection dans les descendances
- sélection dans le germplasme tempéré × tropical
- sélection de populations à cycle intermédiaire
- évaluation du plasma germinatif local
- sélection pour la tolérance à la sécheresse
- test régional d'adaptation de maïs dans les zones semi-arides (SARMAT)
- test de maïs à teneur élevée en proteines
- agronomie: essais de billons cloisonnés, essais de rotations maïs légumineuse; étude de la réponse de l'azote et du phosphore; essais des résidus, de fertilisation, effet des lits de semence sur le rendement du maïs, effet du binage sur le rendement du maïs, méthodes de préparation du sol, étude de toposéquence, étude du buttage, essais de densité de semis.

Pour l'IRAT les actions de Recherches sont:

- l'étude du composite Y d'origine Africaine créé par l'IRAT
- maintien du pool génique du matériel végétal Africain
- obtention d'un composite rustique et bien adapté
- création d'un composite Z de variétés introduites complémentaire de Y sur le plan de l'hétérosie en vue de la création d'hybrides
- le comportement de nouvelles variétés fournies par le CIMMYT.
- l'architecture de la plante: accumulation de gènes mineurs pour réduire la taille des variétés qui présentent un développement végétatif excessif avec une hauteur d'insertion de l'épi elevée qui provoquent la verse ou la casse des tiges en fin de cycle.
- le cycle: création de variétés précoces (moins de 100 j de cycle) avec un potentiel de rendement voisin de celui de la variété tardive (100 à 125 j)
- la résistance aux maladies: transfert de gène de résistance à la rouille et H maydis dans les variétés améliorées.
- la création de variétés (populations améliorées, composites homogeneises) avec une bonne stabilité de rendement.
- la création d'hybrides (intervariétaux ou complexes) utilisables si possible en deuxième gènération sans perte de vigueur. Les hybrides seront destinés aux nouveaux périmètres irrigués et aux vallées de la volta.
- la qualité du grain: grain semi denté pour l'alimentation humaine et denté pour l'industrie de transformation.

Le programme national Burkinabè de recherches sur le maïs comporte les volets suivants:

- Tests d'évaluation des nouvelles introductions
- Tests d'évaluation des variétés locales collectées
- Sélection portant sur les populations locales
- Création d'hybrides et de composites

Au Cap-Vert le programme de Recherches est assez jeune il comprend les actions de recherches suivantes:

- évaluation de matériels locaux et test de matériels introduits
- amélioration des écotypes locaux et création de composites et de synthétiques
- multiplication et diffusion de matériels locaux et introduits.

En Gambie, la recherche couvre essentiellement le volet tests variétaux avec la collaboration d'organismes nationaux, régionaux et internationaux. Les critères qui déterminent l'acceptabilité d'une variété en matière de sélection sont:

- Un bon potentiel de rendement à partir de tests variétaux
- La tolérance à la sécheresse et la résistance aux maladies
- Un volet agronomie s'intéresse aux essais de datés du semis, fumure, densité, restauration et conservation des sols, tests d'herbicides.

Au Mali, le programme de Recherches sur le maïs est principalement basé sur les expérimentations d'adaptation à partir d'essais veriétaux reçus d'organismes régionaux et internationaux (CIMMYT, IRAT, IITA, SAFGRAD, INSAH etc. . .). Depuis quelques années le programme a fait beaucoup de progrès et s'intéresse essentiellement à:

- la recherche de variétés à grain jaune ou blanc corné ou semi-corné
- la recherche de variétés précoces et intermédiaires (90-110 j et 120 j)
- la recherche de variétés à haut potentiel de rendement et stables
- la recherche de variétés résistantes aux maladies, à la verse, à la casse
- la recherche de maïs de taille réduite (2 m à 2,50 m) avec un bon niveau d'insertion de l'épi
- la recherche de variétés résistantes à la sècheresse
- la création de composites avec du matériel prospecté par la CMDT
- participer à la création du composite Z complémentaire du composite Y par exploitation de l'hétérosis entre les deux matériels.

En Mauritanie le programme de Recherches sur le maïs est jeune et les premiers essais ont débuté en 1976.
Le programme de Recherches comprend actuellement:

- l'amélioration de la population locale MAKA
- l'introduction de variétés à travers des essais provenant d'organismes internationaux.
- l'hybridation de la variété locale avec des variétés introduites
- la sélection pour l'obtention d'une variété MAKA sucrée (Maka × Tengold III)
- le test de variétés tolérantes à la sècheresse et à la verse. Ce volet pourrait également inclure la recherche de variétés tolérantes aux hautes températures et aux vents chauds
- des études portant sur les lits de semence, la densité, la fumure selon

les différents types de sols pourraient constituer des axes de recherche surtout pour le maïs irriqué

- multiplication des semences de la population locale MAKA, de MAKA sucré, de Pirsabak 7930, de pool 16 Gusau, de Kogoni B, de Jeka et de J.F. de Saria.

Au Niger à part les essais variétaux qui y sont menés dans le cadre de la collaboration entre ce pays et les organismes régionaux et internationaux il n'y a pas à proprement parler de programme de Recherches.

Au Sénégal, la recherche a mis au point différents cultivars qui répondent aux besoins exprimés par les paysans. Ces cultivars varient selon les degrés de technicité des producteurs c'est ainsi que:

- pour les paysans définis comme étant la cible 1 c'est-à-dire des producteurs pratiquant l'agriculture intensive avec tout ce que cela comporte de technologie avancée, la Recherche a crée des hybrides variétaux pour mieux valoriser la culture du maïs.
- pour les paysans cible 2, qui sont des agriculteurs pratiquant la culture semi-intensive du maïs et pour ce groupe des variétés synthétiques et des composites sont crées
- enfin les paysans constituant la cible 3 sont ceux qui pratiquent la culture traditionnelle du maïs et des populations locales améliorées sont mises à leur disposition.

Le programme de recherche reflète donc le souci de créer un large évantail de cultivars pour s'adapter aux différents modes de culture. Le programme comporte donc les actions suivantes:

- Introduction variétale (lignées pures, populations) et test de leur aptitude à la combinaison avec le composite A.
- Création d'un composite local à large variabilité génétique et sélection dans ce composite A.
- Création de composites de variétés introduites B et D
- Séléction recurrente reciproque pour l'aptitude spécifique à la combinaison entre les composites A et B et A et D.
- Recherche d'un maïs à haute teneur en lysine et tryptophane
- Création d'une variété synthétique à partir de matériels introduits
- Création de variétés et composites à cycle de 10 j pour la zone sud
- Création d'un composite précoce de 70–75 j pour la zone centre nord
- Création de composites blanc et jaune dentés pour l'industrie de transformation
- Amélioration de populations locales.

Pour le maïs irrigué le programme est constitué essentiellement d'introductions de matériels à partir d'organismes régionaux et internationaux et test de ces matériels pour leur comportement avant d'entreprendre des actions d'amélioration.

Du point de vue agronomie des essais de dates de semis, lit de semence (labour + semis à plat, labour + buttage au 30è jour, labour + billons simples avant semis, labour + billons cloisonnés) densités de semis de 37.000 à 62.000 pieds/ha.

Au Tchad les recherches intéressent des tests variétaux qui provienent d'organismes collaborant avec le pays. Les études en agronomie sont initiées. Ces tests consistent à sélectionner des variétés adaptées aux différentes écologies du Tchad et à faire la multiplication des semences.

Il existe beaucoup de problèmes au niveau de la recherche elle même bien qu'elle ait pour vocation de solutionner les problèmes du monde rural.

A l'examen des différents programmes de recherche il ressort que, pour certains une des priorités est la formation des chercheurs pour mieux asseoir la recherche ou une orientation des programmes. C'est là à mon avis que les organismes régionaux et internationaux devraient mettre l'accent pour aider les pays à mettre sur place une équipe de chercheurs multidsciplinaire.

Le second goulot d'étranglement dans la bonne marche de la recherche est le manque notoire de moyens. Même au niveau de certains programmes nationaux qui semblent fonctionner correctement, le manque de moyens aussi bien matériels que financiers se fait sentir souvent lourdement. La solution serait que les programmes nationaux bénéficient des retombées des moyens importants dont disposent les organismes régionaux et internationaux car il faut le dire ces organismes bien que fournissant un effort louable pour aider les programmes nationaux, ne peuvent pas à eux seuls résoudre tous les problèmes de ces derniers, il faudrait l'intervention d'autres tiers ou l'entraide dans la complémentarité des programmes nationaux.

Les programmes nationaux ne peuvent pas attendre tout de l'extérieur, il faudrait qu'ils fassent l'effort de solutionner à leur niveau certains problèmes bien que la situation actuelle vécue par les pays sahéliens soit très difficile. Il est également vrai que certains résultats obtenus par les organismes régionaux ou internationaux déteignent sur les programmes nationaux mais ces organismes pourraient faire un effort supplémentaire en prenant en charge les coûts au moins des essais qu'ils implantent dans les différents pays car il ne sert à rien scientifiquement de donner des essais alors que l'on sait que les moyens ne suivent pas. Leur aide ne fera que renforcer la coopération entre ces organismes et les programmes nationaux.

Si nous examinons bien les programmes de recherche des pays sahéliens, il y a un dénominateur commun qui est la création ou l'introduction de variétés précoces. Ceci est effectivement important si l'on sait l'effet néfaste de la sècheresse. L'accent au point de vue recherche devrait être mis sur:

- La réaction des variétés à la sécheresse, aux maladies, aux insectes
- Des études sur les techniques culturales pour une meilleure rentabilisation de la culture du maïs, labour, fertilisation, lits de semence, date de semis, amendements, contrôle des adventices, techniques de valorisation de l'eau, dispositifs anti-erosifs etc.
- Des études sur les actions post-récoltes, les filières de commercialisation et de stockage.

La création de variétés tolérantes à la sècheresse est particulièrement nécessaire dans la zone Sahélo-soudanienne où les pluies deviennent de plus en plus courtes et erratiques. Tandis que dans la zone Nord-guinéenne bien que les variétés tolérantes à la sècheresse soient encore indisponibles, il s'y ajoute le problème de maladies particulièrement, le streak virus, la rouille et l'helminthosporium maydis qui prennent un caractère plus aigu dans ces zones. Le but de la recherche étant prospectif, c'est le moment de penser à créer des variétés résistantes aux maladies qui commencent à s'installer. Il est vrai qu'il existe certains problèmes d'helpminthosporium, de physioderma et de curvularia qu'il ne faudrait pas négliger non plus.

L'étude des pratiques agronomiques a son importance car dans la plupart des cas, la production du maïs est extensive avec tout ce que celà comporte de déterioration du capital foncier.

Une gestion plus rationnelle de ce capital est urgente si on veut améliorer la production et lutter contre la désertification. Une mécanisation et une motorisation doivent faire l'objet de recherches pour améliorer la productivité aussi bien de l'homme que de la terre.

Les recherches ne doivent pas être seulement thématiques, il faudrait avoir une approche systémique pour permettre un développement harmonieux de l'agriculture. Celà suppose également d'intégrer l'agriculture, l'élevage et la foresterie.

Enfin toutes ces recherches devront nécessiter la collaboration aussi bien du chercheur, des agents de développement que du paysan et devront avoir pour cadre d'évolution des cellules recherche-développement pour un meilleur transfert des technologies.

Conclusion

La production du maïs au niveau de l'Afrique est insuffisante, elle est encore plus faible au niveau des pays Sahéliens. Malgré les progrès enregistrés pour sa culture; la demande reste encore importante bien que des potentialités de production existent au niveau des pays. Un effort supplémentaire devra être fait pour arriver à l'autosuffisance alimentaire comme le veulent le plan d'action de Lagos d'avril 1980 et la déclaration de Hararé de juillet 1984. Une solidarité et une complémentarité dans le domaine scientifique sont nécessaires pour éviter toute dispersion d'efforts et de moyens pour faire des pays sahéliens des greniers céréaliers particulièrement de maïs.

Dans ce cas il est important d'intensifier l'agriculture qui réclame dans nos conditions une technicité qui doit ête encore plus élevée qu'en régions tempérées à cause de la nécessité de maïtriser ou de contrôler des phénomènes dont la dynamique est très accelerée: les cycles biologiques et biochimiques des sols sont rapides, les variations thermiques brusques, les pluies très brutales et agressives, les risques de dégradation élevés et les techniques archaïques ou mal utilisées. L'homme Africain n'est pas imperméable au progrès et a une bonne capacité d'adaptation. En mettant les moyens et un bon encadrement à sa disposition, il est capable de relever son niveau de productivité, ceci est aussi valable pour la recherche que le développement et la production.

Les recherches devront être thematiques tout en se mouvant dans un cadre système de production pour analyser les différentes contraintes qui se posent à l'échelle de l'exploitation et leur chercher des solutions. Les cellules recherche-développement seront privilégiées dans toutes les actions de développement car l'augmentation de la productivité nationale passe par une valorisation des acquis de la recherche par la développement et une programmation de la recherche à partir des contraintes du milieu et en accord avec le développement.

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20 Cowpea Improvement for Semi-Arid Regions of Sub-Saharan Africa

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Introduction

Drought and high temperatures make the semi-arid regions of sub-Saharan Africa an extremely harsh environment for the rainfed production of food crops. This paper reviews the research of a collaborative project between the University of California, Riverside and the Institut Senegalais de Recherches Agricoles, which is developing improved cowpea varieties for this harsh environment.

Extent of Drought in Semi-Arid Africa

In recent years, droughts have been severe in the regions of Africa where cowpea is a major crop. Average rainfall in northern Senegal since 1968 has been only 269 mm, compared with a long-term average prior to 1968 of 447 mm (Table 1). The amount of water required for maximum grain yield by cowpeas presently grown in this region varies from 400 to 500 mm, depending on the cycle length of the varieties (Table 1, Dancette and Hall, 1979). In years with rainfall as low as 200 mm, grain yields of cowpea were substantially reduced compared with wetter years, and pearl millet and peanut produced very little grain (Figure 1). Analyses of rainfall and potential evapotranspiration data for the semi-arid Sahelian zone crossing Africa from northern Senegal to western Sudan (Figure 2) indicate that the average length of the cropping season can vary from 60 days, close to the Sahara desert, to 120 days at the wetter boundary to the south. Also, the amount of rainfall and length of the cropping season vary substantially from year to year (Table 1).

In other semi-arid regions of Africa, the rainy season is long but highly unreliable (e.g., Sebele, Botswana in Figure 2) or bimodal with substantial droughts occurring between two short rainy seasons (e.g., Katumani, Kenya in Figure 2). Different types of cowpea varieties are needed for these contrasting environments.

Breeding Cowpeas with Improved Adaptation to Drought

Cowpea is one of the few crops that can withstand the extreme droughts that have devastated the Sahel during the last 18 years. The ability of cowpeas to produce a few 100 kg of grain when pearl millet and peanut have failed to

Table 1 Rainfall and Water Requirement Data for Locations at the Dry and Wet Boundaries of the Main Cowpea Production Zone in Senegal (from data of C. Dancette).

Locations	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
	Annual Rainfall (mm/year)																	
Louga	212	599	253	294	156	290	381	310	297	168	350	252	280	253	215	151	174	208
Bambey	360	696	553	572	377	402	471	494	391	383	689	558	402	505	452	318	460	398

	Mean Rainfall				Six years out of ten annual rainfall estimated to be within this range*	Estimated water requirements of cowpea for maximum grain yield		
	Arithmetic			Geometric		Early** varieties	Senegal Varieties	
	1918-85	1918-67	1968-85	1968-85			Bambey 21	58-57
Louga	400	447	269	253	189 to 339	344	401	459
Bambey	618	671	471	460	383 to 554	352	403	453

* Calculated using log-transformed data from 1968-85.

** Early varieties include CB5, 1-2-1, 1-11-1, 1-12-3, 3-4-1, and 3-4-13 from UCR; and IT82E-18, IT82E-56, and IT82E-60 from IITA; and have cycle lengths of 60 days under dry (at Louga) conditions and 70 days under wet (at Bambey) conditions. The cycle lengths for Bambey 21 are 70 (at Louga) and 80 (at Bambey) days, and for 58-57 are 80 (at Louga) and 90 (at Bamber) days.

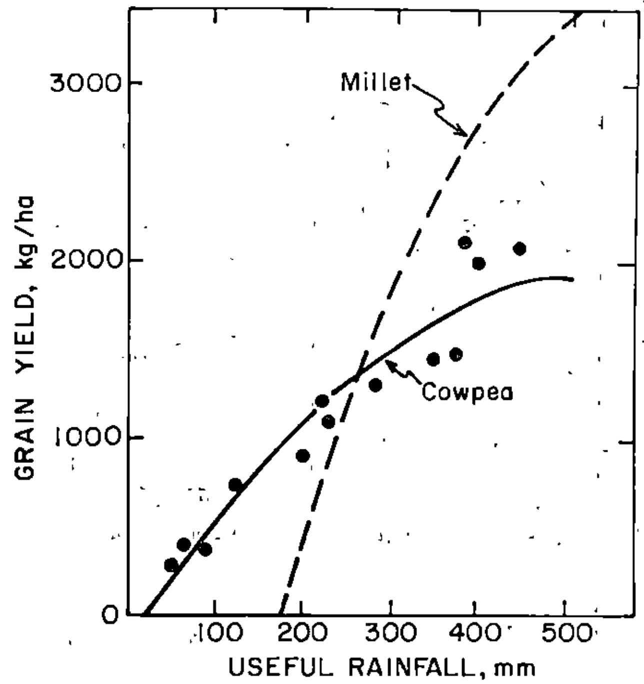

Figure 1 Grain yields of cowpea (variety Bambey 21) and millet (variety Souna III) obtained in field experiments at Louga and Bambey in Senegal over several years (Ndoye et al., 1984).

produce any grain has earned this crop the name "crop of security" for farmers in northern Senegal. Recent research has shown that cowpea varieties can be developed that are more productive under these harsh conditions.

Developing Shorter-Cycle Varieties

Cowpea varieties presently grown in Sahel require a growing season of 80 to 120 days. Hydrologic budget analyses of the type made by Dancette and Hall (1979) indicate that varieties with shorter cycles, requiring only 65 days from sowing to maturity, would be more effective than traditional Sahelian cowpeas at the drier boundary of the semi-arid zone.

In developing shorter-cycle varieties, strains were selected with earlier flowering and a shorter vegetative stage, because this should not reduce yield potential and performance in wetter years as much as selecting for a shorter reproductive period. Through field and controlled-environment studies, it was demonstrated that cowpeas selected for early flowering in hot, long day conditions (e.g., in Imperial Valley, California in the summer) should be completely insensitive to photoperiod and flower relatively early over a broad range of environments (Dow el-madina, 1985). A day-neutral variety from Senegal (Bambey 23), that has early, synchronous flowering was crossed with a more robust early-flowering variety from California (California Blackeye No. 5). Trangressive segregants with early synchronous

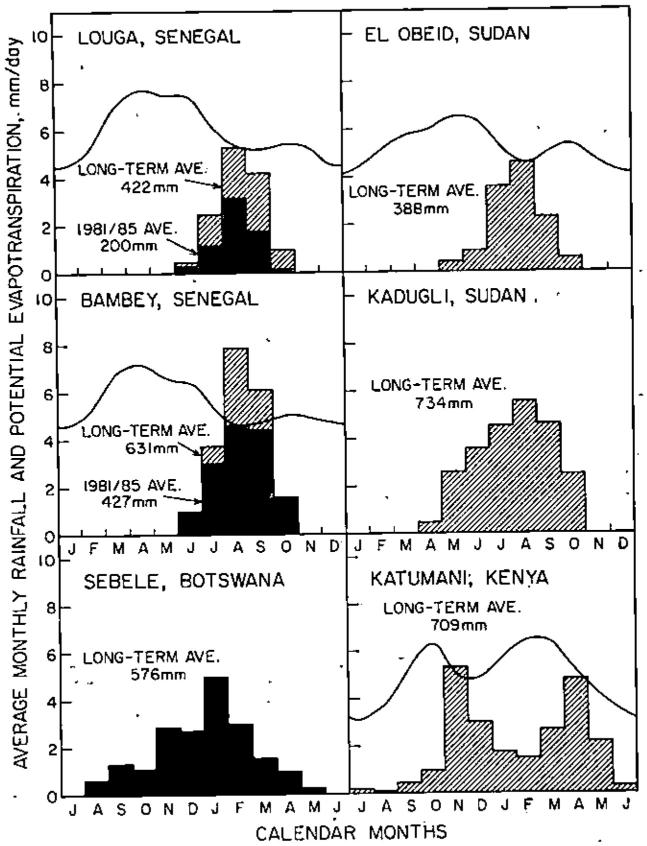

Figure 2 Long-term average rainfall at Louga (1918/77), Bambey (1921/80), El-Obeid (1941/70), Kadugli (1951/80), and Katumani (1956/80), recent rainfall and potential evapotranspiration.

flowering in California were selected. These selections begin flowering 36 days from sowing in Senegal, and have a cycle length of 60 days with late season drought and 70 days under well-watered conditions. Several of these selections have been more productive than local cultivars in dry years in Senegal and Sudan, and have reasonable yield potential in wetter locations (Table 2). Many short-cycle varieties developed by IITA, IT82E-18 and IT82E-56, flowered early and gave good yields under dry conditions in Senegal in 1983 (Cisee et al., 1984).

Catastrophic droughts occurred in northern Senegal in 1982, 1983 and 1984, and reserves of food and seeds were depleted. The Government of Senegal decided to expand the area of cowpea and millet under cultivation in the Louga Region, and reduce the area sown to peanut. With the assistance of the EEC and USAID, 650 metric tons of cowpea seed (CB5) were imported from California and distributed to farmers. The project was successful in the north of Senegal. These early cowpeas produced substantial quantities of food during the period of hunger just prior to the main cereal harvest in late September. Rainfall was low in 1985 (Table 1) but well distributed and national cowpea production was increased 4-to-5-fold compared with earlier years.

Table 2 Comparison of Early and Local Cowpeas

	Senegal*				Sudan**
	1982		1983		1983
	Bambey	Louga	Bambey	Louga	El Obeid
Useful Rainfall (mm)	452	181	315	135	230
Cowpea strains	Grain Yields (kg/ha)				
Selections from CB5 x Bambey 23					
1-2-1	2324	663	1315	250	468
1-11-1	2290	949	1253	188	
1-12-3	2406	1091	1816	206	500
3-4-1	2033	919	1445	290	
3-4-13	2418	1026	1422	216	355
Parents					
CB5	2354	922	1355	195	625
Bambey 23			1066	131	
Local varieties					
Bambey 21	2263	699	1303	51	
Garnel Kabish					135
Gambaru					169
LSD .05	NS	213	NS	81	170

* N. Cisse, S. Thiaw, M. Diop, and A. Sene.
** Western Sudan Agricultural Research Project

For the Sahelian zone, early cowpeas have both advantages and disadvantages. With a short rainy season, they can produce as much as 1800 kg/ha grain within 60 days with only 200 m of rain (Table 2). They also produce food during the period of hunger as either edible pods, fresh-shelled peas, or dried grain. However, they do not produce as much hay as the Sahelian varieties and may not be desirable in parts of Mali where hay can be more valuable than grain. Present early cowpea varieties have less capacity to recover from droughts at early flowering compared with varieties, such as 58-57 from Senegal, that are more prostrate and more indeterminate. In wetter years, the pods of early varieties may mature during wet weather and be devastated by pod rots.

Due to the extreme variability of rainfall in semi-arid Africa, it would be advisable for farmers to sow both early, erect, synchronous-flowering varieties and medium cycle, more prostrate, sequential-flowering varieties. In some circumstances, varietal intercrops with alternating rows of these two types of cowpea varieties (rotated with pearl millet) may be more effective than sole crops of each variety or intercrops of different species. Farmers in certain parts of the Sahelian zone whose present cowpea varieties require more than 100 days from sowing to maturity and produce low yields in dry years (e.g., western Sudan in Table 2) could substantially benefit from growing early cowpea varieties.

Developing Varieties with Improved Drought Resistance

Breeding for resistance to drought has been difficult because it requires the incorporation of several characters. In addition, the important characters are difficult to select and they must be incorporated at levels of expression and in combinations that suit specific target regions (Hall, 1981). Some progress has been made with some characters that should confer drought resistance in specific water-limited environments.

In the wetter part of the semi-arid zone, water is often available deep in the soil profile which is only fully accessible to varieties with deep roots. A method has been developed for screening cowpeas for genotypic differences in rooting under field conditions (Robertson et al., 1985). The method is based upon the time at which symptoms first appear in leaves as an indication of when roots reach a herbicide band placed deep in between rows of plants. Some diverse cowpeas have been screened (Hall and Patel, 1985) and revealed that certain genotypes (Bambey 21 and California Blackeye No. 3) may be useful as parents for conferring improved rooting. Attempts are being made to combine the deep rooting of CB3 with the superior partitioning of assimilate of 8006, which is a breeding line developed at the University of California, Davis. Improved capacity for rooting would be particularly useful in dense or dry soils which have high resistance to root growth, and where increased root growth increases the amounts of water and nutrients available to plants.

Varieties with improved seasonal water-use efficiency would produce more biomass in dry environments, if they also have sufficient canopy development and root growth to extract much of the available moisture in the soil profile. However, earlier methods for evaluating water-use efficiency were laborious under field conditions. Recent theoretical and experimental studies have demonstrated that levels of the heavy isotope carbon-13 (compared with carbon-12) in dried leaf tissue provides a rapid and sensitive measure of relative, integrated, instrinsic water-use efficiency for some species (Farquhar and Richards, 1984). Farquhar's method is now being used to screen cowpeas for water-use efficiency, and genotypic differences under drought, have been discovered.

Increases in grain yield of determinate cereal crops have been associated with increases in harvest index. It is more difficult to quantify harvest index in indeterminate crops like cowpea. By visual selection, cowpea strains have been detected which had higher harvest index and higher grain yield under stored soil moisture (Hall and Grantz, 1981). Visual selection for high harvest index can be conducted in developing the more determinate type of cowpeas that can be useful where a single harvest of grain is desirable and forage is less important. Selecting for anatomically fixed determinancy is not recommended because it provides no opportunity for recovery after stresses during midseason.

Evaluating the Adaptation to Drought of Different Cowpea Strains

Adaptation to drought depends upon many interacting plant characteristics and progress in plant breeding should be monitored. Multi-location yield trials are a necessary part of breeding programs, and trials in dry sites can provide approximate measures of differences in drought adaptation among advanced lines. Systems for providing controlled levels of available water can be used to provide more direct evaluations of drought adaptation at one location in one season, and speed up the process of breeding improved varieties. The line-source sprinkler has been proposed as a method for imposing different levels of available water. Unfortunately, this approach is not efficient for evaluating drought-adaptation of advanced lines due to methodological and statistical problems that constrain data analysis, and the water regimens and droughts imposed by the line-source sprinkler are unnatural.

A method has been evaluated that can be used where surface irrigation is available, the land is reasonably flat, and horizontal transfer of water in the soil is not substantial. The experimental design consists of paired wet and dry plots in strips across the field (split blocks). Plants were grown on single-row beds, with adjacent four row, wet and dry plots. The central furrow of the wet plots was irrigated with sufficient frequency to maintain an adequate supply of water to the two center rows which were harvested to determine yield of the wet plots. All of the other furrows receive natural rainfall or limited irrigation. The two center rows of the dry plot were harvestd to determine yield. It was possible to obtain a statistical ranking of the varieties for yield under wet and dry conditions, the difference in yield between wet and dry conditions, and average yield over wet and dry conditions (Table 3). Average yield was probably the most useful criterion for selecting varieties providing the wet and dry regimens were reasonably representative of the wetter and drier years occurring in the target region. Some cowpea strains with high average yields (1-2-1 and CB5) have performed well in semi-arid Africa (Table 2) indicating that this method may be effective for evaluating the drought adaptation of advanced lines.

Table 3 Yield Trial to Evaluate Drought Adaptation Conducted at Riverside, 1985

Identification	Irrigation Regime Complete*	Irrigation Regime Deficit	Yield Reduction	Average Yield
	kg/ha			
1-2-1	2662 ab	1352 a	1310	2007 a
Chino M1	2972 a	998 be	1974	1985 a
CB5	2655 ab	981 be	1674	1818 ab
8006	2331 bc	1090 ae	1241	1710 ac
DEBY/E16	2086 ce	1309 ab	777	1698 ac
1-8-5	2295 bd	1099 ae	1196	1697 ac
DEBY/C17	2344 bc	1023 ae	1321	1684 ac
DEBY/A31	1986 cf	1118 ad	868	1552 ad
1-2-5	1906 cg	1179 ac	727	1542 ae
1-12-12	1833 ch	1075 ae	758	1454 be
DEBY/E17	2012 cf	858 ce	1154	1435 be
DEBY/A2	1902 cg	962 ce	940	1432 be
DEBY/E22	1872 ch	989 be	883	1430 be
2-3-15	1659 eh	1089 ae	570	1374 be
DEBY/A23	1607 eh	972 be	635	1290 ce
DEBY/D22	1728 dh	844 ce	884	1286 ce
1-1-13	1506 fh	1012 be	494	1259 ce
DEBY/A34	1556 eh	814 de	742	1185 de
DEBY/A21	1321 h	928 ce	393	1124 de
3-4-1	1391 gh	761 e	630	1076 e
$LSD_{.05}$	420	250	–	308

* The complete treatment was irrigated every week, whereas the deficit treatment was irrigated every third week.
Means in a column with different letters are significantly different at the 5% level.

Cowpea Responses to Temperatures Occurring in Semi-Arid Africa

Day air temperatures are extremely high in the Sahelian zone during the season when cowpeas are grown (refer to data for Senegal and Sudan in Figure 3). This results in a high evaporative demand (Dancette and Hall, 1979) which subjects plants to atmospheric drought. The Sahelian zone also has high air temperatures during the night (Figure 3) and our research has shown that this can cause abnormal flower development and low pod set. In controlled environments, it was demonstrated that high night temperatures cause male sterility and can be more detrimental to pod set (Warrag and Hall, 1984b) than high day air temperature or high soil temperature (Warrag and Hall, 1984a). Using enclosures and heaters, cowpeas were subjected to different night temperatures under field conditions (Nielsen and Hall, 1985a). Night temperatures occurring in the Sahel can result in pod set of only 30% to 40% of total flowers produced, compared with 50% to 60% in subtropical zones with lower night temperature, and reduce yield by approximately 1 ton/ha (Nielsen and Hall, 1985b).

Breeding Cowpeas with Improved Heat Tolerance at Flowering

Breeding to incorporate heat tolerance during early flowering can be used to partially overcome the problem of excessive flower abscission and low pod

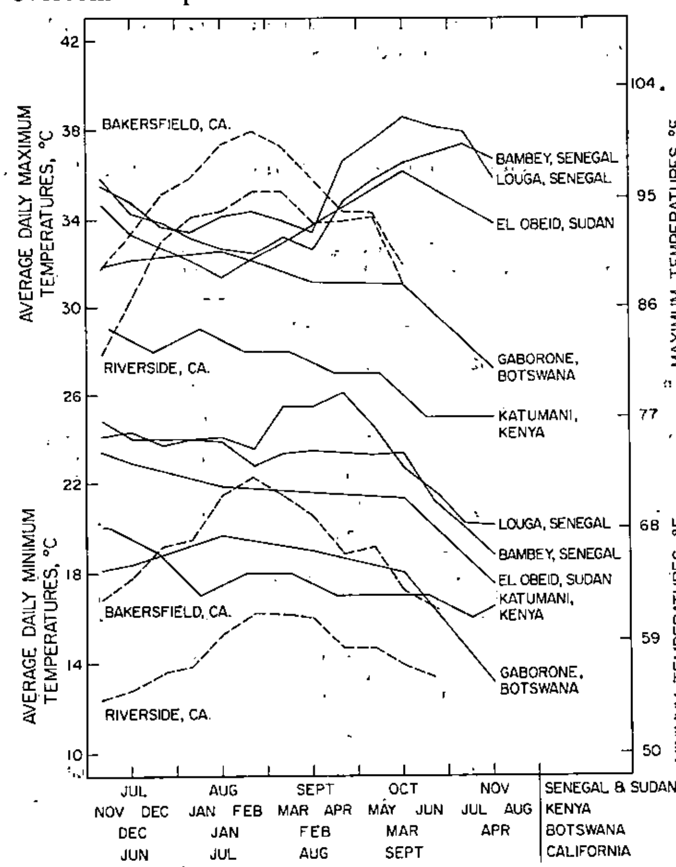

Figure 3 Average daily maximum and minimum air temperature during the seasons when cowpeas are grown in specific locations in California (----) and Africa (———).

Floral buds appeared early				Floral buds appeared late	Floral buds did not appear during hot weather
Tolerant during floral bud development producing many flowers			Sensitive during floral bud development and flowering producing no flowers or pods	Moderately sensitive during floral bud development and highly sensitive at flowering, producing a few flowers but no pods	
Tolerant at flowering producing many pods	Moderately sensitive at flowering, producing fewer pods	Highly sensitive at flowering, producing very few pods			
Prima TVu 4552	UCR 193 UCR 194 UCR 204 UCR 206 UCR 207 UCR 240 UCR 241 IT82D-885 IT82D-889	7964 Bambey 23 Magnolia 8006 8043 PI 293497 PI 339593 CPI 45576 IT82E-18 IT82E-77 IT81D-703 TVx 3236-01G Laura B Cross 1-6E-1 Queen Anne	CB5 CB77 TVx 12-01E PI 218123 PI 302457 PI 352830	Bambey 21 Mougne Ndiambour 58-57 TVx 1948-01E TVx 1836-013J Vita 1 Vita 3 Vita 4 Vita 5 TKx 9-11D TKx 133-16D-2 4R-0267-1E TVx309-1G Hercules Colossus 80 Mississippi Silver IT81D-716 IT81D-1020 IT81D-1064	KN-1 Suvita-2 TN 88-63 IT81D-985 IT82E-3

Table 4 Responses of Contrasting Cowpea Strains to High Temperatures (and long days) During the Summer in Imperial Valley, California (P.N. Patel)

set. Two cowpea strains from West Africa, TVu 4552 and Prima, have substantial heat tolerance at flowering and can set substantial numbers of pods in extremely hot field conditions where many other cowpeas have been unable to produce pods (Warrag and Hall, 1983; Nielsen and Hall, 1985b). Studies by P.N. Patel have shown that at least two genetic systems are needed to confer heat tolerance at flowering, and he has classified cowpeas into six groups with respect to their responses to hot, long-day conditions (Table 4). A single recessive gene enables cowpeas to produce flowers under extremely hot long-day conditions in Imperial Valley, California. This gene may not be needed to promote flower production in the hot but shorter-day conditions of the Sahel. The second genetic system is probably important under Sahelian conditions. It confers tolerance during flower development preventing male sterility and promoting pod set when night temperatures are high.

A pedigree breeding program has been used to incorporate the heat tolerance of TVu 4552 and Prima into CB5 and several African cowpeas, 58-57, Bambey 21, Mougne, Ndiambour, and IT823-18. Segegrating progeny were screened for ability to set pods under high temperatures in Imperial Valley, and in subsequent generations they have been screened for agronomic characters in Riverside, California and Bambey, Senegal. Yield tests under extremely hot conditions in Imperial Valley, California (Table 5) indicate that progress is being made in incorporating heat tolerance into a CB5 genetic background and advanced lines from other crosses are being tested in Senegal.

Night temperatures vary in the semi-arid regions of Africa where cowpeas are produced (Figure 3). They are similar to California at higher elevations (e.g. Katumani, Kenya) and more extreme latitudes (e.g., Gaborone, Botswana) in Africa. In contrast, night temperatures are much higher in the Sahel and low elevation areas of West Africa, and greater heat tolerance is needed in these regions.

Table 5 Yield Trials under Extremely Hot Conditions in Imperial Valley, California, 1985

Identification	Cross	Sowing Date of Trial Mar 15	Apr 30	Jun 15
		------------kg/ha----------		
*HFPS1233	CB5xPrima	835 ab	363 a	245 a
HFPS/325	CB5xPrima	714 ab	327 a	233 a
HFTS/246	CB5xTVu4552	758 ab	280 a	230 a
HFTB/518	CB5/CB5xTVu4552	931 a	232 ab	223 a
7964(UCD)	CB5xMagnolia	951 a	221 ab	198 ab
HFTB/502	CB5/CB5xTVu4552	922 a	238 ab	195 ab
HFPS1134	CB5xPrima	470 b	206 ab	149 b
CB5 (Mackie)	CBxIron	775 ab	66 b	38 c
LSD.05		377	165	63

* HF denotes a line selected for heat tolerance at flowering. Temperatures during flowering were progressively hotter for the later sowing dates with maximum and minimum daily air temperatures during July 16 to August 13 averaging 42°C (108°F) and 23°C (73°F), respectively.
Means in a column with different letters are significantly different a the 5% level.

Conclusions

Early flowering, short-cycle cowpeas have been shown to contribute to the stablity of crop production systems in the Sahelian zone of Africa. However, these cowpea varieties have several disadvantages and farmers should also grow sequential-flowering, medium-cycle cowpeas that produce more hay and have the ability to recover from mid-season drought and respond to late rains. Developing varieties of cowpeas with improved adaptation to the harsh conditions of the Sahel will require incorporation of the many characters that confer resistance to drought, tolerance to heat, and resistance to the other environmental and biological stresses that can occur. Continued close collaboration among the cowpea breeding programs of the International Institute of Tropical Agriculture, the University of California, Riverside, and the National Programs in Africa is essential to develop the improved cowpea varieties needed by farmers in the Sahel.

Acknowledgement

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21 Varietal Evaluation of Cowpea to Determine Characters Associated with Adaptation to Dry Areas in Africa

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Abstract Fifteen cowpea varieties were grown at two dates of planting at two locations, Kamboinse (Sudan Savanna) and Pobe (Sahel) in Burkina Faso, West Africa to evaluate them for their adaptation and to determine which plant characters are associated to yield in dry areas. Varieties which produced large dry matter, particularly when planted late, were found to be better yielders. In addition, number of pods per plant were positively and highly correlated with grain yield. However, due to reasonably well distributed rains, differences between locations for grain yield were not as pronounced as expected.

Introduction

Cowpea (*Vigna unguiculata* L. Walp) is one of the most important grain legumes grown and consumed in the semi-arid areas of West Africa. The major producing countries are Nigeria, Niger, Burkina Faso, Mali and Senegal. Although it is adapted to relatively dry conditions, yet its yields are greatly influenced by frequent dry spells caused by low and erratic rainfall. The damage is particularly high when the drought coincides with flowering and or pod filling stage. In addition to the amount and distribution of rainfall, high soil and atmospheric temperatures and sand blasts common in the Sahel, are important factors determining the adaptation of varieties in the dry areas.

For several years, the average rainfall has considerably declined in many regions of the semi-arid tropics. The rains also tend to stop early, making varieties traditionally grown in these areas less adapted. It is, therefore, necessary to identify or develop varieties that can adapt better to the changing climatic conditions in the areas. With this objective in mind, a set of varieties, early to medium in maturity (60-80 days) with erect to semi-erect and spreading plant type, were evaluated in 1985 at two locations in the dry areas of Burkina Faso. Correlation coefficients between different characters were calculated to find out which of these were important in producing higher yields in these areas. Such information helps in identifying varieties from the breeding material. The climatic conditions in West African countries, south of Sahara are similar, and therefore, the results obtained in Burkina Faso are expected to be applicable to other countries.

Materials and Methods

The experiment contained 15 varieties originating from IITA, Nigeria (TVx 3236, IT82D-716, IT82E-60 and IT82D-952), IITA/SAFGRAD in Burkina Faso (KVx 30-309-6G, KVx 30-305-6G, KN-1 and SUVITA-2), Brazil (1-2-1 and 8047) and various national programmes in the West African region, i.e. Niger (TN 88-63), Senegal (58-57 and Mougne), Nigeria (IAR 48) and Cape Verd (Santiago local). Many of these varieties have been tested in the dry areas before, and their reaction was known e.g. SUVITA-2 and 58-57 are adapted to dry areas whereas IT82E-60 and KN-1 are not. The trial was planted at two locations namely Kamboinse (L1), representing Sudan Savanna (600-900 mm annual rainfall) and Pobe (L2), representing Sahel (300-600 mm) at two dates of planting. At Kamboinse, it was planted on 27 June (D1) and 12 July (D2) and at Pobe on 3 (D1) and 12 (D2), July, 1985. The experimental design was a complete randomised block, with 4 replications. The plot size was 4 rows, 4 m long with distance between and within the rows 0.75 m and 0.40 m, respectively. Observations were taken on five randomly selected plants in the central two rows. Means of these were used for the statistical analysis. Data were recorded on days to flowering, grain yield (gm) per plant, dry plant weight (gm), harvest index (ratio of grain yield and plant dry weight), pod length, number of pods per plant, seeds per pod, 100 seed weight, and threshing percentage. Correlation coefficients were calculated using the formula of Little and Hills (1975).

Results and Discussion

The observations made on different characters are reported in Table 1 and their analysis of variance in Table 2. Highly significant differences were observed for varieties for all the characters suggesting that the varieties included in the experiment were highly variable. Significant location effects were found for flowering, harvest index, pod length, number of pods per plant, seeds per pod and threshing per cent. Variety x Location effects were highly significant only for flowering and plant dry weight and significant for number of pods and no effect on grain yield. This showed that except for number of pods per plant, and to some extent for plant dry weight, the location effects were not appreciable for other important characters generally associated with yield. This probably happened because of a reasonably well distributed rainfall at both the locations where the drought had little or no effect. The overall dates of planting effects, were highly significant for flowering, grain yield, harvest index and number of pods per plant, suggesting the importance of date of planting in the performance of varieties. The interaction of Varieties x Dates of planting was absent for all the characters, but a highly significant Location x Dates of planting effect was observed for grain yield and pods per plant, the two most important plant characters in a variety.

Because of good rains at both the locations, the performance of varieties in general was quite similar. However, the varieties known to be better adapted to dry areas, e.g. SUVITA-2, 58-57, KVx 30-305-3G, TVx 3236 etc., gave higher yields than others. The varieties 1-2-1, 8047 IT82E-60, Santiago local and KN-1 yielded poorly at Pobe, the driest location, confirming our earlier observations on some of these varieties (IITA/SAFGRAD, 1983, 1984).

The correlation coefficient studies (Table 3) indicated that the dry plant weight was significantly correlated with yield at the late date of planting (D2) at both locations. The late planting is usually subjected to more drought stress and this showed that the plants with more vigour (high dry matter) were better adapted to dry environments. This confirmed our earlier

Table 1 Analysis of variance of 15 cowpea varieties planted at two dates at two locations in 1985, Burkina Faso.

Source of variation	DFF	Mean Squares								
		Days to flowering	Grain Yield/ plant (gm)	Single plant dry wt. (gm)	Harvest Index	Pod length (cm)	N°. of pods/Plant	Seeds/ pod	100 Seed wt. (gm)	Threshing %
Varieties	14	145.3**	894.3**	619.8**	0.80**	37.6**	997.5**	40.3**	301.5**	212.9**
Locations	1	173.3**	242.0	275.5	1.91**	11.7**	608.3**	38.4**	5.5	296.0**
Dates	1	405.1**	1416.3**	105.6	2.91**	2.2	1206.4**	10.4	0.1	54.0*
Var. x Loc.	14	37.7**	128.1	204.9**	0.12	1.3	126.9*	2.3	1.2	12.2
Var. x Dates	14	6.3	100.9	173.7	0.24	2.2	102.1	3.2	1.7	13.5
Loc. x Dates	1	51.3**	1386.9**	266.4	0.00	10.0**	1049.5**	0.2	1.0	9.9
Var. x Loc. x Dates	14	3.6	114.1	131.7	0.16	1.6	116.9	3.1	3.8*	13.1
Error	180	4.2	98.0	107.7	0.14	1.5	68.9	2.7	1.9	10.3

* Significant at 5% level of probability.
** Significant at 1% level of probability.

Table 2 Comparison of different plant characters of 15 cowpea varieties at Kamboinse (L1) and Pobe (L2), Burkina Faso, 1985 under two dates (D1 and D2) with respect to adaptation in dry areas.

Variety	Days to flowering				Grain Yield/Plant (gm)				Single Plant Dry Wt. (gm)				Harvest Index				Pod Length (cm)			
	L1		L2		L1		L2		L1		L2		L1		L2		L1		L2	
	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2
KVx 30-309-6G	47	43	46	45	38	43	33	43	36	24	33	27	1.1	1.8	1.0	1.6	14	10	12	13
KVx 30-305-3G	47	45	48	49	47	46	40	50	39	24	30	33	1.2	1.9	1.3	1.5	13	12	13	13
TVx 3236	46	42	45	41	46	32	43	49	30	19	35	41	1.5	1.7	1.2	1.2	14	13	13	13
58-57	47	43	47	42	41	36	35	57	27	26	41	49	1.5	1.4	1.4	1.2	14	13	13	14
TN 88-63	45	40	44	43	34	49	30	36	28	32	29	26	1.2	1.5	1.0	1.4	11	11	10	11
MOUGNE	45	43	43	41	34	38	30	37	23	31	30	40	1.5	1.2	1.0	0.9	15	16	16	16
IT 82D-716	44	43	38	37	39	36	27	39	28	20	22	27	1.4	1.8	1.2	1.4	14	13	13	13
IT 82E-60	36	39	37	35	24	21	22	31	23	19	20	23	1.0	1.1	1.1	1.3	14	15	15	16
IT 82D-952	46	42	43	43	37	36	31	33	33	23	25	29	1.1	1.6	1.2	1.1	12	12	12	14
1-2-1	42	40	34	34	34	18	19	26	27	15	21	22	1.3	1.2	0.9	1.1	15	13	14	14
8047	42	38	36	34	31	28	15	25	21	17	16	20	1.5	1.6	0.9	1.3	14	14	14	15
IAR 48	44	39	41	40	35	49	36	54	27	37	30	35	1.3	1.3	1.2	1.5	14	14	15	14
SANTIAGO LOCAL	44	39	40	37	26	40	18	22	30	48	20	23	0.9	0.8	0.9	1.0	15	16	18	17
KN-1	46	41	45	46	31	28	23	34	41	36	58	36	0.8	6.8	0.4	0.9	14	14	15	15
SUVITA-2	47	44	46	44	42	41	35	45	38	27	37	32	1.1	1.5	0.9	1.4	13	12	12	12
Trial Mean	44	41	42	41	36	36	29	39	30	26	30	31	1.3	1.4	1.1	1.3	14	13	14	14
C.V. %	9.5	5.4	5.1	4.3	25.1	35.3	20.6	23.9	32.1	39.8	41.2	25.1	24.0	34.0	28.5	24.1	12.9	9.2	7.4	4.9
L.S.D. 5%	2.9	1.6	1.5	1.2	12.4	17.6	8.3	12.8	13.2	14.6	16.9	10.7	0.2	0.4	0.2	0.2	1.2	0.8	0.7	0.5

Table 2 cont'd.

Variety	Nº Pods/Plant				Seeds/Pod				100 Seed Wt. (gm)				Threshing %			
	L1		L2		L1		L2		L1		L2		L1		L2	
	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2
KVx 30-309-6G	27	30	23	28	8	8	8	8	23	22	22	22	80	83	81	80
KVx 30-305-3G	26	27	20	31	8	8	11	8	24	24	25	25	83	85	81	84
KVx 3236	44	35	35	42	10	7	10	11	11	14	12	11	78	78	74	82
58-57	38	40	37	63	10	8	9	9	11	12	11	10	76	79	73	74
TN 88-63	32	58	33	38	8	8	9	9	12	11	11	11	81	82	79	82
MOUGNE	36	27	23	29	7	8	10	9	16	15	15	15	75	76	73	73
IT 82D-716	36	33	26	37	8	8	8	7	14	15	14	14	83	81	78	78
IT 82E-60	19	16	18	23	7	7	8	7	19	19	17	19	77	79	74	76
IT 82D-952	37	36	26	30	9	7	10	10	11	14	13	12	78	81	78	79
1-2-1	22	18	17	23	7	6	8	6	21	20	20	21	80	79	81	78
8047	30	26	13	24	7	7	7	8	19	19	17	20	85	78	74	76
IAR 48	23	30	21	35	7	8	9	9	22	21	21	20	80	82	79	79
SANTIAGO LOCAL	20	29	12	16	13	13	14	13	11	12	12	12	73	71	69	70
KN-1	26	20	15	22	10	10	11	11	15	15	17	14	71	76	69	72
SUVITA-2	32	33	26	34	8	7	8	8	19	19	18	18	83	82	81	82
Trial Mean	30	30	23	31	8	8	9	8	16	17	16	16	79	79	76	78
C.V. %	26.0	34.0	19.7	27.3	15.9	29.2	21.4	19.0	5.5	11.7	9.6	4.6	4.3	4.1	3.7	3.3
L.S.D 5%	5.3	7.2	3.1	5.9	0.9	0.4	1.3	1.2	0.6	1.3	1.1	0.5	2.3	2.2	1.9	1.8

Table 3 Correlation coefficients (r) between different plant characters of cowpea at two dates of planting (D1 and D2) at Kamboinse (L1) and Pobe (L2), 1985.

Character		Grain yield per plant (gm)	Dry plant weight (gm)	Pod length (cm)	Pods per plant	Seeds per pod	100 seed weight (gm)	Threshing %	H'vst Index
Days to flowering	D1L1	0.715**	0.637**	-0.266	0.520*	0.340	-0.162	-0.006	0.085$_{*}$
	D2L1	0.335$_{**}$	-0.166$_{**}$	-0.438	0.168$_{*}$	-0.163	0.135	0.457	0.528*
	D1L2	0.768$^{**}_{*}$	0.698**	-0.372	0.524*	0.309	0.019	0.067	-0.002
	D2L2	0.565*	0.505	-0.451	0.259	0.248	0.027	0.381	0.190
Grain yield per plant (gm)	D1L1		0.430$_{*}$	-0.270	0.628$^{*}_{**}$	-0.042	0.070	0.413	0.440
	D2L1		0.524*	-0.347	0.646$_{**}$	0.287	-0.013	0.394	0.346
	D1L2		0.403$_{**}$	-0.460	0.713$_{**}$	0.041	0.105	0.385	0.499
	D2L2		0.771**	-0.490	0.781**	-0.061	0.017	0.455	0.476
Dry plant weight (gm)	D1L1			-0.284	-0.033	0.329$_{**}$	0.141	-0.111	-0.584*
	D2L1			0.355	0.182	0.860**	-0.349	-0.446	-0.584*
	D1L2			-0.129	0.279	0.200	0.003	-0.230	-0.554*
	D2L2			-0.103	0.726	0.283	-0.377	-0.033	-0.181
Pod length (cm)	D1L1				-0.268	0.111	0.179	-0.351$_{**}$	0.144$_{**}$
	D2L1				-0.489$_{**}$	0.408	-0.224	-0.782**	-0.701**
	D1L2				-0.653**	0.513	0.023	-0.660**	-0.245$_{**}$
	D2L2				-0.487	0.320	-0.028	-0.844**	-0.658**
Pods/plant	D1L1					0.080	-0.552$^{*}_{*}$	0.114	0.608*
	D2L1					0.013	-0.547*	0.276	0.377
	D1L2					-0.196	-0.469	0.225	-0.323
	D2L2					-0.073	-0.407	0.265	0.244
Seeds/Pod	D1L1						-0.647**	-0.597*	-0.369$_{*}$
	D2L1						-0.377	-0.614$^{*}_{*}$	-0.542*
	D2L2						-0.214$_{*}$	-0.519	-0.118$_{*}$
	D2L2						-0.597*	-0.400	-0.528*
100 seed weight (gm)	D1L1							0.460$_{*}$	-0.053
	D2L1							0.546$_{*}$	0.322
	D1L2							0.534*	0.119$_{*}$
	D2L2							0.346	0.522*
Threshing %	D1L1								0.429$_{**}$
	D2L1								0.762**
	D1L2								0.513$_{**}$
	D2L2								0.750**

* Represents significance at 5% level of probability.
** Represents significance at 1% level of probability.

observations where plants with short stature (low dry matter) e.g. IT82E-60 were found to be poor yielders in the dry areas (IITA, 1984). This was also true in this experiment when varieties with low plant dry weight e.g. 1-2-1, 8047 and IT82E-60 produced low yields. The other character which was significantly and positively correlated with grain yield was pods per plant. This observation has also been reported by Singh and Mehndirata (1969), Aggarwal *et al* (1982), Aryeetey and Laing (1963) and Ebong (1973) for cowpea. The harvest index (ratio of seed weight to plant weight) was also positively correlated with yield, but not significant. Part of the problem was that certain varieties, in spite of their low yields, managed to give a higher harvest index by producing inferior plant weight than grain yield e.g. 8047, IT82E-60 and 1-2-1. This may therefore not be a good character to select for.

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22 Breeding Cowpea Varieties for Drought Escape

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Introduction

The sub-Sahara northern Africa and parts of east and southern Africa form the semi-arid zone where success of crops is entirely dependent upon the adequacy and regularity of rainfall. For the last few years, except 1985, the rainfall in this region has been grossly inadequate leading to large scale crop failure, mass starvation and malnutrition. Even the drought tolerant crops such as millet, sorghum, groundnut and cowpeas which are primarily grown in that region have succumbed to intermittent drought and early cessation of rainfall. This has been partly due to the late maturity of traditional varieties which suffer from irregular rainfall not only during the vegetative growth phase but also during the reproductive phase, when the rains stop suddenly. The International Crop Research Institute for Semi-Arid Tropics (ICRISAT) and the International Institute of Tropical Agriculture (IITA) are working in close collaboration with the Semi-Arid Food Grain Research and Development (SAFGRAD) Project of OAU and various national programs to develop drought tolerant and early maturing varieties of these crops with a view to minimize yield losses due to unreliable rainfall and short rainy seasons. Breeding cowpea varieties for drought resistance has been established as one of the long term goals by IITA since it involves identification and incorporation of a number of physiological, morphological and phenological traits with complex inheritance into a single variety. In the meantime, considerable efforts are being made to develop early maturing cowpea varieties which would tend to escape drought during the reproductive phase. This paper describes the ongoing strategy and progress made so far.

Rainfall Pattern in the Semi-Arid Regions of Africa

West Africa

Virmani, Reddy and Bose in 1980 compiled elaborate climatic data for different countries in West Africa. Based on their data, a summary of mean monthly rainfall across different locations falling in specific latitudinal belts is presented in Fig. 1. These data indicate that rainfall decreases with increasing northern latitude. The region between 12-13°N latitude representing the sudano-sahelian belt receives reasonably reliable rainfall during the months of July and August. Further north, the rainfall is less and less and beyond 16°N latitude it becomes too short and unreliable for crop production. It should thus be possible to grow extra-early varieties maturing between 60-70 days upto 15°N latitude with good chance of success. Coupled with early maturity, cowpea varieties with deep root systems, semi-determinate growth habit and other adaptive traits, would tolerate a brief spell of drought during the growing season.

East Africa

Parts of Sudan, Ethiopia, Somalia, Kenya and Tanzania receive less than 600 mm annual rainfall and very often the crops are exposed to drought stress. In some countries, particularly in Somalia, Kenya and Tanzania, certain regions have bimodal rainfall characterized by a relatively longer rainy season followed by a short rainy season. A typical example of bimodal rainfall in Tanzania is depicted in Fig. 2 where the long rainy season occurs from March to June and the short rainy season is from November to January with December being the reliable rainy month. In the drier regions, the traditional varieties of maize, sorghum or cowpeas invariably suffer from drought stress, and short rainy seasons. However, given 40-50 days of reliable rainfall, the short duration varieties can be successfully grown in these areas.

Southern Africa

The rainfall pattern in parts of southern Africa covering Zimbabwe, Botswana and Mozambique is very similar to the sahelian belt of West

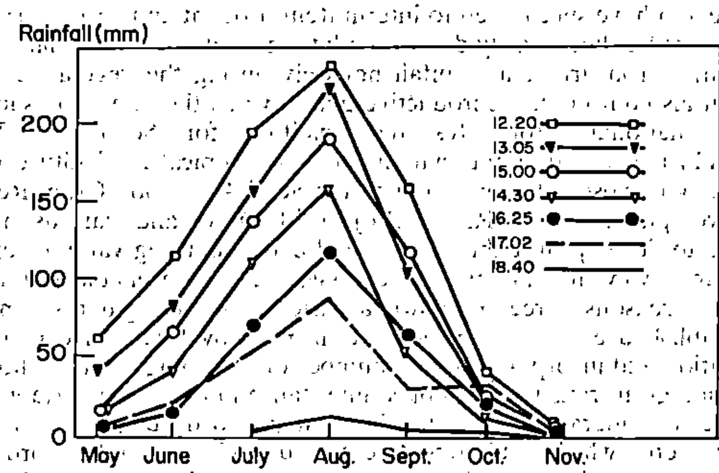

Figure 1 Mean monthly rainfall at different latitudes of West Africa

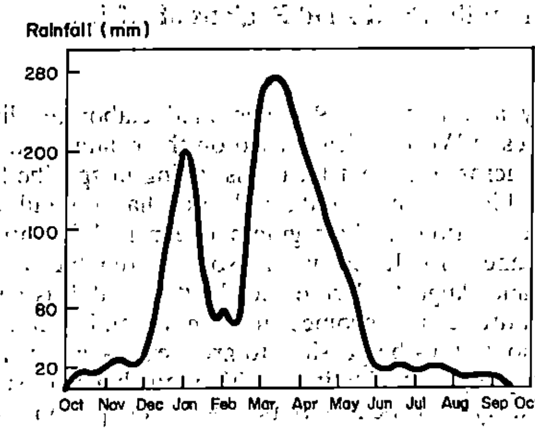

Figure 2 Rainfall pattern at Ilonga, Tanzania

Africa and causes widescale crop failure due to drought stress. Monthly rainfall data at different locations in Botswana are presented in Fig. 3. The total rainfall is low and variable at all the locations but a 40-50 day period between December to February is reasonably wet to permit cultivation of early maturing varieties.

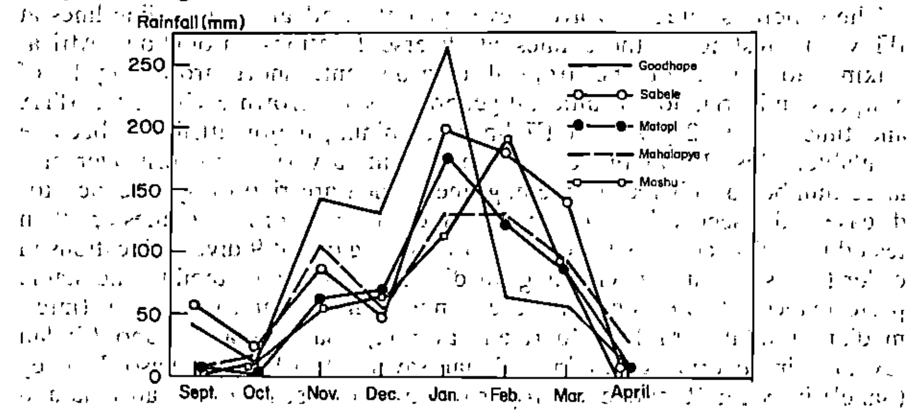

Figure 3 Monthly rainfall at different locations in Botswana 1980/81

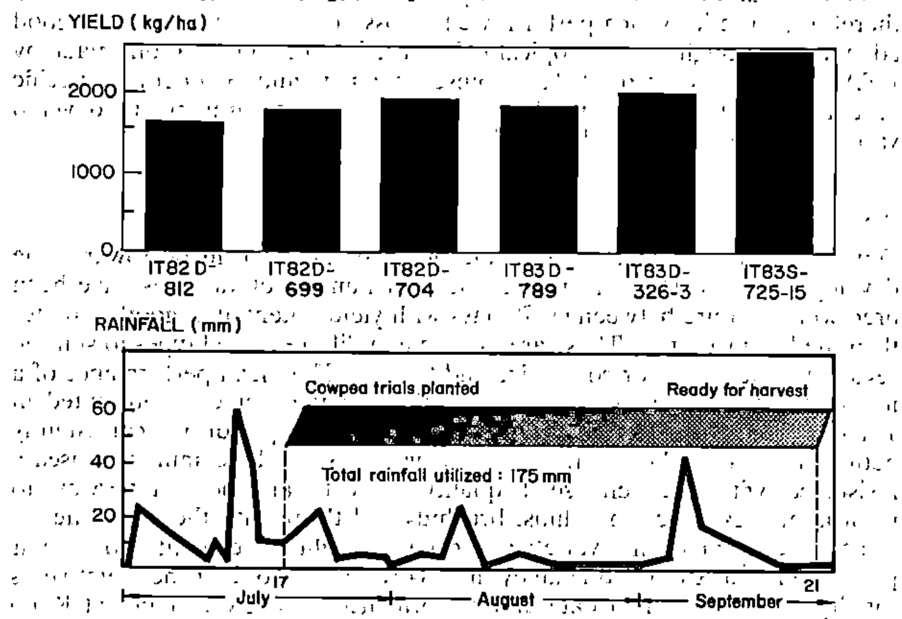

Figure 4 Rainfall at Kano and performance of selected cowpea varieties, 1984

Strategy for Breeding Cowpea Varieties for Drought Escape

Cowpeas form an integral part of the cropping system in all the semi-arid regions of Africa, often grown in mixtures with sorghum and millet. However, the traditional varieties are normally photosensitive and late maturing and consequently, suffer during the early cessation of rains. Therefore, the International Institute of Tropical Agriculture (IITA) initiated a systematic programme to develop photoinsensitive early maturing varieties of cowpea which would escape drought and increase the chances of a successful crop in the drier regions. The major objective of this work is to shorten maturity period from 100-130 days of traditional varieties to 60-70 days and incorporate traits such as photoinsensitivity, deep root system, fast initial growth, heat tolerance and semi-determinate growth habit.

The general strategy involves development of advanced breeding lines at IITA and testing of these lines at diverse locations throughout Africa. Taking advantage of the tropical environment, short growth cycle of cowpeas and irrigation facilities, 4 generations are grown each year at IITA and thus, within 2 years, F6/F7 lines combining major attributes become available. This '2 year breeding cycle' permits a very rapid turn over of a large number of advanced breeding lines which are rigorously screened for disease and insect resistance. The selected advanced breeding lines are then tested by IITA scientists located in different regions at 9 diverse locations in order to ensure further screening for diseases, wider adaptability and stable performance. These locations are Onne (high rainfall), Ibadan (intermediate rainfall), Mokwa (derived savanna), Samaru and Kano (Sudan savanna) in Nigeria, Kamboinse (Sudan savanna) in Burkina Faso, Niamey (Sahel) in Niger Republic, Morogoro (short rainy season) in Tanzania and Harare in Zimbabwe. The environments of these 9 locations represent agro-climatic conditions of the major cowpea growing regions of the tropics and therefore, varieties which perform well across all these locations show good adaptation throughout the tropical belt. Based on the observations made by IITA scientists located at Kamboinse, Niamey and Morogoro, specific parents are selected and used in a hybridization programme to develop varieties specifically suitable to drier environments.

Breeding for Early Maturity

During the last 5 years, considerable progress has been made towards the development of early maturing varieties. A number of varieties have been bred which mature between 60-70 days with yield potential as good or better than the local varieties. These are available in different seed types to suit the regional preferences for color, size and texture. The mean performance of a few extra-early varieties across 50 locations in the tropics is presented in Table 1. IT 82E-18, IT 82E-32, and IT 82E-16 have performed consistently better at most of the locations. These varieties combine multiple disease resistance with excellent seed quality. Efforts are now underway to incorporate resistance to aphids, bruchids and thrips into these varieties.

That early maturing varieties escape drought is evident from their performance at Kano and Niamey in 1984 which was one of the worst years for dryness. The rainfall data and performance of a few varieties at Kano are presented in Fig. 4. The crop was planted on July 17 and harvested on September 21; total rainfall during the growing season was 175 mm. The yields ranged from 1.5 to 2.5 tons per hectare. The adjacent fields which had millets, groundnuts and local cowpea varieties did not produce anything due to drought in late September and October.

Performance of a few early maturing cowpea varieties at Niamey is presented in Table 2. The total rainfall between May to September at Niamey in 1984 was 260 mm, which was 54% below normal. However, July had near reliable rainfall and permitted a successful crop of early maturing cowpea varieties. The crop was planted at Niamey on July 2, 1984 and harvested within 64 days. Most of the early maturing varieties yielded between 1 to 1.5 tons per hectare while the local variety – 'Sadore' dried

Table 1 Mean perforamnce of Extra-Early varieties of cowpea distributed to various national programs in 1984

Variety	Rank Frequency				Mean yield* kg/ha
	Ist	2nd	3rd	4th	
IT 82E-18	12	8	8	4	1419
IT 82E-32	5	7	7	9	1354
IT 82E-16	9	5	7	9	1346
IT 82D-812	1	7	6	6	1271
IT 82D-885	7	6	6	3	1260
IT 82D-789	3	3	5	5	1225
IT 82E-60	1	1	2	1	985
IT 82D-889	2	2	2	1	964
Local Checks**	2	-	3	4	1206

* Mean of 50 locations across the tropics.
** Check varieties differed from location to location

Table 2 Performance of selected early maturing cowpea varieties at Niamey in 1984*

Variety	Days to		Yield kg/ha
	Flower	Maturity	
IT 82E-60	34	56	991
IT 82E-16	39	62	991
IT 82D-713	40	63	1231
IT 82D-716	39	62	1332
IT 82D-703	39	64	1598
Sadore local	56	78	185

* IITA, 1984.

prematurely and the adjacent fields of millets also succumbed to drought (IITA, 1984a).

Other examples of drought escape by early cowpea varieties are from Tanzania and Botswana. Most of the maize planted in Tanzania during the short rainy season die prematurely due to the dry spell in February but under the same conditions, early cowpea varieties mature normally and yield upto 1.5 tons/ha. The good performance of an early maturing cowpea ER-7 at different locations in Botswana inspite of the short rainy seasons, further illustrates the effectiveness of early maturity in minimizing crop losses in drought prone areas.

Breeding for Deep Root System and Semi-Determinate Growth Habit

Early maturing varieties require about 40 days of drought free weather to ensure initial establishment, good vegetative growth and normal flowering and podding. This is achieved by planting these varieties just before peak rainy season. In normal years this would ensure successful crop yields. However, in some years and particularly in the sahelian zone, brief spells of dry weather occur even during the peak rainy months. Therefore, varieties having shallow and small root systems with erect, determinate growth habit suffer more damage than indeterminate varieties which have greater recovering capacity after the end of the dry spell. Concerted efforts are being made, therefore, to incorporate deep and dense root systems with semi-determinacy into early maturing varieties. This will permit cowpea plants to take moisture from the deep soil strata during dry spells and also provide additional flowering nodes if the first flush of flowers have been affected by drought.

Preliminary studies have revealed a great deal of variability for root characteristics in cowpea. Data on root length and root dry weight in respect of a few cowpea varieties are presented in Table 4. IT 82E-60, IT 81D-1020, IT 82D-8123 roots grew significantly faster than others and IT 82E-60, TVx 3236, VITA-3 and IT 82D-716 produced more root mass than others. IT 82E-60, VITA-3, IT 82D-716 and TVx 3236 have performed consistently better in drier regions which might have been partly due to their larger root systems. Further work is in progress to screen more cowpea germplasm lines for deep and dense root system and incorporate this trait into early maturing varieties. A number of early maturing advanced breeding lines have been developed which have semi-determinate growth habit. Unlike the erect, nonbranching, near synchronously maturing varieties, these have a few branches at the base of the plants which provide better ground cover and additional flowering nodes to compensate for flower abortion on the main stem due to drought. These will be evaluated at several locations in coming season.

Breeding for Heat Tolerance

In the typical sahelian environments, the day temperatures may exceed 40°C and coupled with dry weather, this causes reduced seedling growth and flower abortion. Cowpeas perform well between 30-35°C. Screening of cowpea varieties for heat tolerance is being done by CRSP scientists at the University of California, Riverside and several varieties with heat tolerance have been identified. Systematic work similar to this has now been initiated at IITA using growth chambers and efforts are being made to incorporate this trait into early maturing varieties of cowpea.

Table 3 Root characteristics of improved cowpea varieties

Variety	Root length* (cm)	Root dry weight* per plant (g)
IT 82E-60	94.9	1.64
IT 81D-1020	93.5	0.67
IT 81D-812	92.8	0.97
VITA-7	84.3	1.10
IT 82D-716	71.8	1.14
VITA-3	70.5	1.23
TVx 3236	66.5	1.87
LSD 5%	21.7	0.74

* Four weeks after planting.

Breeding for Tolerance to Leaf Damage by Sand Blows

In the drier regions of the sahel, wind storms blow sand particles with considerable force. The sand particles puncture cowpea leaves and retard plant growth. The IITA/SAFGRAD scientists working at Burkina Faso and Niamey have observed considerable variability among cowpea varieties for tolerance to leaf damage by sand particles (IITA 1984b). Efforts will be made, therefore, to screen large numbers of cowpea germplasm lines in these regions to identify the most tolerant varieties and incorporate this trait into early maturing varieties.

The data presented in this paper clearly indicate that breeding for early maturity coupled with deep and dense root system, heat tolerance and other adaptive traits which permit drought escape should be considered as a major strategy for ensuring stable crop production in the semi-arid regions of Africa.

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23 Breeding for Drought and Striga Resistance in Cowpea

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Introduction

Cowpea (*Vigna unguiculata* L. Walp) is one of the most important legume crops grown in Africa, particularly in the semi-arid areas. Nigeria, Niger, Cameroon, Burkina Faso, Mali and Senegal are considered to be the major cowpea producing areas. Although it is adapted to relatively dry areas, yet its yields are greatly influenced by variation in amount and distribution of rainfall. Yield losses are particularly high when drought occurs at flowering or at pod filling stage. Precise estimates are not available, but losses can easily be 50% or more.

Another problem associated with cowpea production in the dry areas is a plant parasite, *Striga gesnerioidesa*. In severe infestation, it can cause total death of the cowpea plant.

The International Institute of Tropical Agriculture (IITA) has a program based in Burkina Faso to breed cowpea varieties resistant to drought and to *Striga*. Progress made and strategies adapted to achieve these goals are described in this paper.

Breeding for Drought Resistance

Climate and Soils

The semi-arid areas of West Africa, where most of the cowpeas are grown can be divided into three distinct climatic zones based on the amount of rainfall and the length of the growing season. The three zones are Northern Guinea Savanna, Sudan Savanna and Sahel Savanna. In the Northern Guinea Savanna, the average annual rainfall varies from 900-1200 mm and the rainy season starts in May and ends in October (4-5 months). In the Sudan Savanna, the annual rainfall varies from 600-900 mm and the growing season extends from mid-June to early October (3-4 months). In the Sahel Savanna, the rainfall varies from 300-600 mm and the growing season extends from the end of June to early September (2-3 months). Drought and *Striga* are problems mostly in the Sudan Savanna and the Sahel areas where rainfall is relatively less and more erratic. Drought spells of 7-10 days or more are fairly common and can occur almost at any time during the crop growth period. In addition to low and erratic rainfall, high atmospheric and soil temperatures and sand blasts are quite common in the Sahel. The damage by sand blast is particularly high when the crop is at the seedling stage. While selecting for drought resistance, therefore special attention is paid to these factors.

Varietal Testing and Stability Analysis

From 1980-1982, a set of 15 cowpea varieties was grown at 8 locations in four different countries in West Africa, representing the three climatic zones and listed in Table 1. Mean grain yield (kg/ha) of each variety at each location was calculated. Stability analysis (Weil and Quoi, 1974, Hildebrand, 1984), where the yield of each cultivar at each site is regressed against the mean site yield was used to analyse the data. The mean site yield represents an environmental index. A site where mean yields are low is considered a poor environment due to annual rainfall conditions and/or location.

Table 1 Locations and their classifications

Location/Country		Classification
Farako-Bâ	- Burkina Faso	Northern Guinea Savanna
Sikasso	- Mali	"
Samaru	- Nigeria	"
Kamboinsé	- Burkina Faso	Sudan Savanna
Bambey	- Senegal	"
Sotuba	- Mali	"
Saouga	- Burkina Faso	Sahel Savanna
Louga	- Senegal	"

The regression equation is given as

$$Y_{ijk} = a + bx_{jk} + e_{ijk},$$

where Y_{ijk} = the yield of variety i at location j during year k, and x_{jk} is the mean trial yield in location j during year k,
and e_{ijk} is the error term. The data were analysed in four categories, i.e. (1) a combined analysis using data from all the sites (Overall Zones), (2) data from the sites in the Northern Guinea Savanna (Zone I), (3) data from the sites in the Sudan Savanna (Zone III), and (4) data from the sites in the Sahel Savanna (Zone III).

Using the estimated regression coefficients, the cowpea varieties were classified separately in each category according to four standard stability types, A through D, as shown in Fig. 1 (Matlon, 1985). Type A represents a variety which has yields superior to the mean trial yields across all environments. Type B represents a variety which has yields superior to the mean yields under poor environments but yields inferior to the mean trial yields under superior environments. Type C represents a variety which has yields inferior to the mean trial yields under poor environments, but yields superior to the mean trial yields under superior environments. Type D represents a variety which has yields inferior to the mean trial yields across all environments.

The ranking of varieties, stability index (b from the regression), stability type (ST), projected cross point (PCOP), coefficient of determination (R^2) and mean grain yield Overall Zones, Zone I, Zone II, and Zone III are

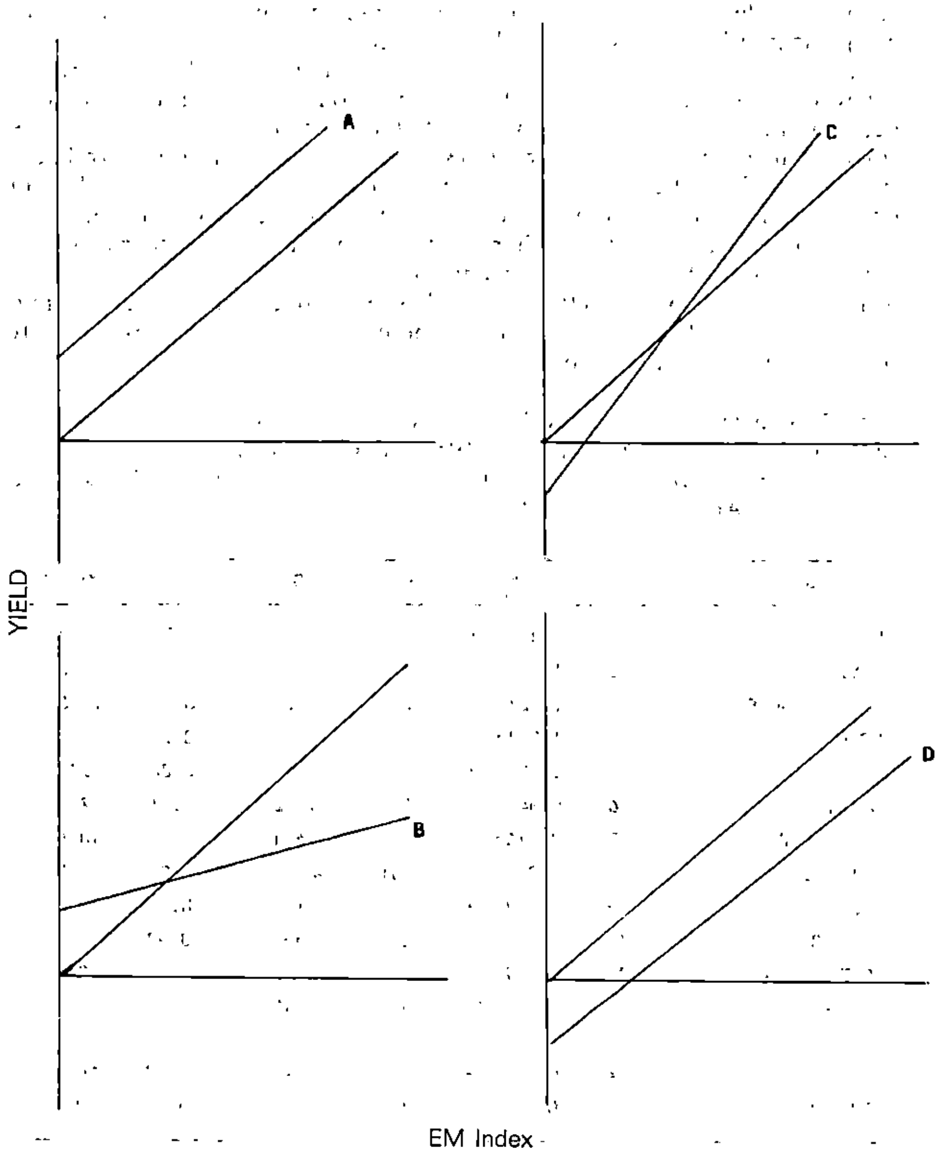

Figure 1 Four stability types

Source: Matlon, 1985.

given in Tables 2, 3, 4 and 5 respectively. Graphic results of the three zones are presented in Figures 2, 3, and 4 respectively.

The most significant result of this analysis was that the ranking of varieties changed from one zone to another. Calculations of the varietal rankings between the respective zones was tested by means of experiment rank correlation coefficients. These were not found to be significantly correlated, suggesting that the varieties which were well adapted to different environments from the point of view of yield stability and overall superiority were not the same. In the higher rainfall areas i.e. the Northern Guinea Savanna (Zone I) and Sudan Savanna (Zone II), the promising varieties were KN-1 and TVx 1948-01F. KN-1 has been released for more humid areas in Burkina Faso, but as indicated here, its performance was generally poor in the dry areas (Zone III).

Table 2 Ranking, stability index (b), stability type (ST), projected cross-over point (PCOP), coefficient of determination (R^2) and mean grain yield (kg/ha) of 15 cowpea varieties during the years 1980-82 over all the three zones in the semi-arid areas of West Africa.

Varieties	Rank	b	ST	PCOP*	R^2	Yield
KN-1	1	1.003 ***	A	-	0.84	1428
SUVITA-2	2	1.141 ***	A	-	0.84	1423
TVx 1999-01F	3	1.222 ***	A/C	> 17	0.87	1496
MOUGNE	4	1.092 ***	A	-	0.91	1364
TVx 1948-01F	5	1.083 ***	A	-	0.88	1334
58-57	6	0.842 ***	B	< 1112	0.63	1209
N'DIAMBUR	7	0.776 ***	B	< 364	0.64	1034
IAR 355	8	0.905 ***	B/D	< 67	0.86	1117
IAR 341	9	0.778 ***	B	< 193	0.53	998
IAR 48	10	1.150 ***	C	> 536	0.90	1331
KPODIGUEGUE	11	1.077 ***	C	> 585	0.81	1277
VITA-4	12	1.112 ***	C	> 1018	0.75	1251
VITA-5	13	0.952 ***	D	-	0.80	1105
RHENOSTAR	14	0.898 ***	D	-	0.78	1088
BAMBEY 21	15	0.974 ***	D	-	0.82	961

* Indicated is the range of grain yields for the mean trial results over which yields for each variety are projected to be superior. Absence of values under this column indicates that PCOP does not occur in case of A and D stability types.

The Type A varieties in the dry zone of Sahel Savanna (Zone III), where drought is a major constraint, were SUVITA-2, 58-57 and N'DIAMBUR. These varieties have consistently performed better in such environments for several years. SUVITA-2 is being considered for release in the dry areas of Burkina Faso and Mali, and 58-57 is already widely grown in the dry areas of Senegal.

Table 3 Ranking, stability index (b), stability type (ST), projected cross-over point (PCOP), coefficient of determination R^2), and mean yield (kg/ha) of 15 cowpea varieties during the years 1980-82 in Zone I of the semi-arid areas of West Africa.

Varieties	Rank	b	ST	PCOP *	R^2	Yield
KN-1	1	1.005 **	A	-	0.77	1437
TVx 1948-01F	2	1.204 ***	A	-	0.97	1299
IAR 341	3	0.728	B	< 1150	0.43	1092
SUVITA-2	4	0.783 **	B	< 1095	0.70	1076
VITA-5	5	0.581	B	< 809	0.32	961
58-57	6	0.765	B	< 430	0.68	920
IAR 355	7	0.801 **	B/D	< 232	0.73	904
TVx 1999-01F	8	1.555 **	C	> 587	0.87	1340
VITA-4	9	1.276 ***	C	> 424	0.67	1249
MOUGNE	10	1.192 ***	C	> 458	0.81	1189
KPODIGUEGUE	11	1.268 ***	C	> 928	0.66	1110
IAR-48	12	1.036 ***	C	> 1111	0.83	1069
RHENOSTAR	13	1.163 **	C	> 1651	0.73	976
N'DIAMBUR	14	0.941 **	D	-	0.53	801
BAMBEY 21	15	0.701 ***	D	-	0.90	641

* Indicated is the range of grain yields for the mean trial results over which yields for each variety are projected to be superior. Absence of values under this column indicates that PCOP does not occur in case of A and D stability types.

Table 4 Ranking, stability index (b), stability type (ST), projected cross-over point (PCOP), coefficient of determination (R^2), and mean yield (kg/ha) of 15 cowpea varieties during the years 1980-82 in Zone II of the semi-arid areas of West Africa.

Varieties	Rank	b	ST	PCOP*	R^2	Yield
TVx 1948-01F	1	1.004 **	A	-	0.73	1807
TVx 1999-01F	2	0.930 **	A/B	< 6990	0.67	2072
MOUGNE	3	0.982 ***	A/B	< 10973	0.85	1868
KN-1	4	0.933 ***	A/B	< 3784	0.81	1841
KPODIGUEGUE	5	0.962 **	A/B	< 4584	0.71	1812
VITA-5	6	0.927 ***	B/D	< 717	0.81	1629
IAR 355	7	0.829 **	B	< 1131	0.76	1604
RHENOSTAR	8	0.729 *	B	< 946	0.56	1504
SUVITA-2	9	1.407 ***	C	> 908	0.81	2024
IAR 48	10	1.193 ***	A/C	> 625	0.81	1909
VITA 4	11	1.057 *	C	> 1207	0.59	1729
58-57	12	1.106 **	C/D	> 2826	0.73	1583
BAMBEY 21	13	1.055 **	C/D	> 4805	0.78	1531
N'DIAMBUR	14	0.8,8 **	D	-	0.68	1354
IAR 341	15	0.992	D	-	0.44	1259

* Indicated is the range of grain yields for the mean trial results over which yields for each variety are projected to be superior. Absence of values under this column indicates that PCOP does not occur in case of A and D stability types.

Table 5 Ranking, stability index (b), stability type (ST), projected cross-over point (PCOP), coefficient of determination (R^2), and mean yield (kg/ha) of 15 cowpea varieties during the years 1980-82 in Zone III of the semi-arid areas of West Africa.

Varieties	Rank	b	ST	PCOP *	R^2	Yield
58-57	1	1.201 **	A	-	0.51	1082
SUVITA	2	1.083 **	A	-	0.74	1039
N'DIAMBUR	3	1.129 *	A	-	0.82	903
KPODIGUEGUE	4	0.740 **	B	< 646	0.79	725
IAR 355	5	0.881 **	B	< 358	0.82	705
RHENOSTAR	6	0.830 **	B/D	< 37	0.79	631
BAMBEY 21	7	0.690	B	< 217	0.55	586
MOUGNE	8	1.337 **	C	> 398	0.95	871
TVx 1999-01F	9	1.240 **	C	> 271	0.97	867
IAR 48	10	1.183 ***	C	> 178	0.97	857
KN-1	11	1.237 ***	C	> 568	0.90	795
TVx 1948-01F	12	1.005 ***	C/D	> 15659	0.88	678
VITA-5	13	0.842 **	D	-	0.94	536
VITA-4	14	0.853 **	D	-	0.94	535
IAR 341	15	0.745 **	D	-	0.94	465

* Indicated is the range of grain yields for the mean trial results over which yields for each variety are projected to be superior. Absence of values under this column indicates that PCOP does not occur in case of A and D stability types.

Additional Promising Varieties

In addition to these varieties several more have been tested across environments in West Africa up to 1985. A variety, TVx 3236, developed at IITA, Nigeria has performed well across the three zones. It has become quite popular in northern Nigeria (Kano, ADP) and is also expected to be released in Mali and Burkina Faso. TN-88-63, developed by the national program in Niger, and three sister lines, KVx 30-309-6G, KVx 30-305-3G and KVx 30-470-3G developed by IITA/SAFGRAD in Burkina Faso from a cross of SUVITA-2 x TVu 2027, have also performed well for the last several years in Sudan Savanna (Zone II) and Sahel (Zone III) areas (IITA/SAFGRAD Annual Reports, 1982, 1983, 1984 and 1985). TN 88-63 is currently being tested in collaboration with the Institute of Sahel (INSAH), (INSAH, 1985) at farm level by national programs in Mali, Burkina Faso, Niger, Gambia, Cape Verde and Senegal. The three sister lines, KVx 30-309-6G, KVx 305-3G and KVx 370-3G have been selected for further tests in Mali and Burkina Faso.

In addition, a new series of crosses have been made by the IITA/SAFGRAD program. The early generation materials tested in 1985 at Kamboinse (Sudan Savanna) and Pobe (Sahel) have produced several promising varieties. Also new promising varieties have been identified from the germplasm screened in 1985 (IITA/SAFGRAD Annual Report,1985). Further tests are planned in future on these varieties.

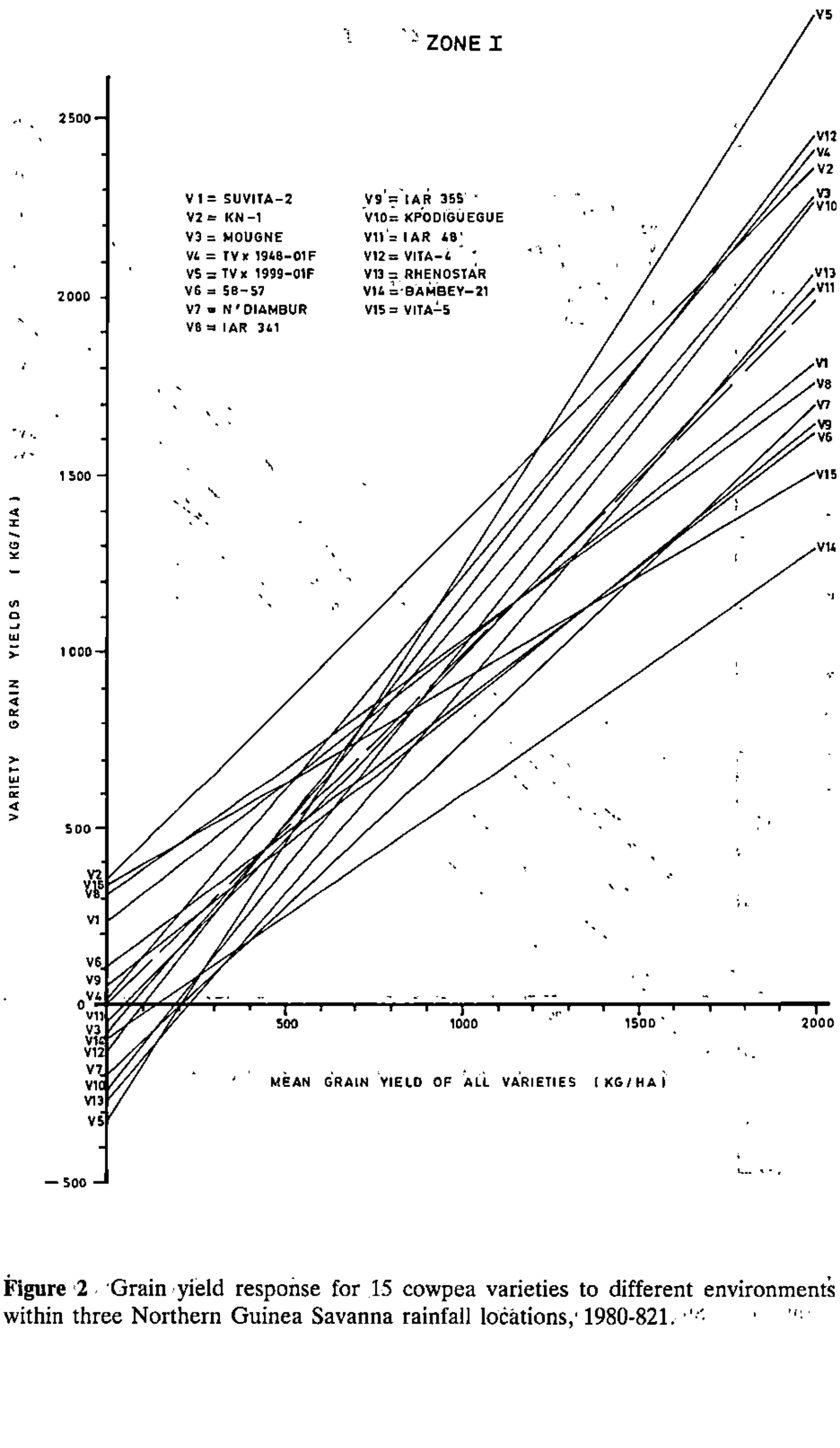

Figure 2 Grain yield response for 15 cowpea varieties to different environments within three Northern Guinea Savanna rainfall locations, 1980-821.

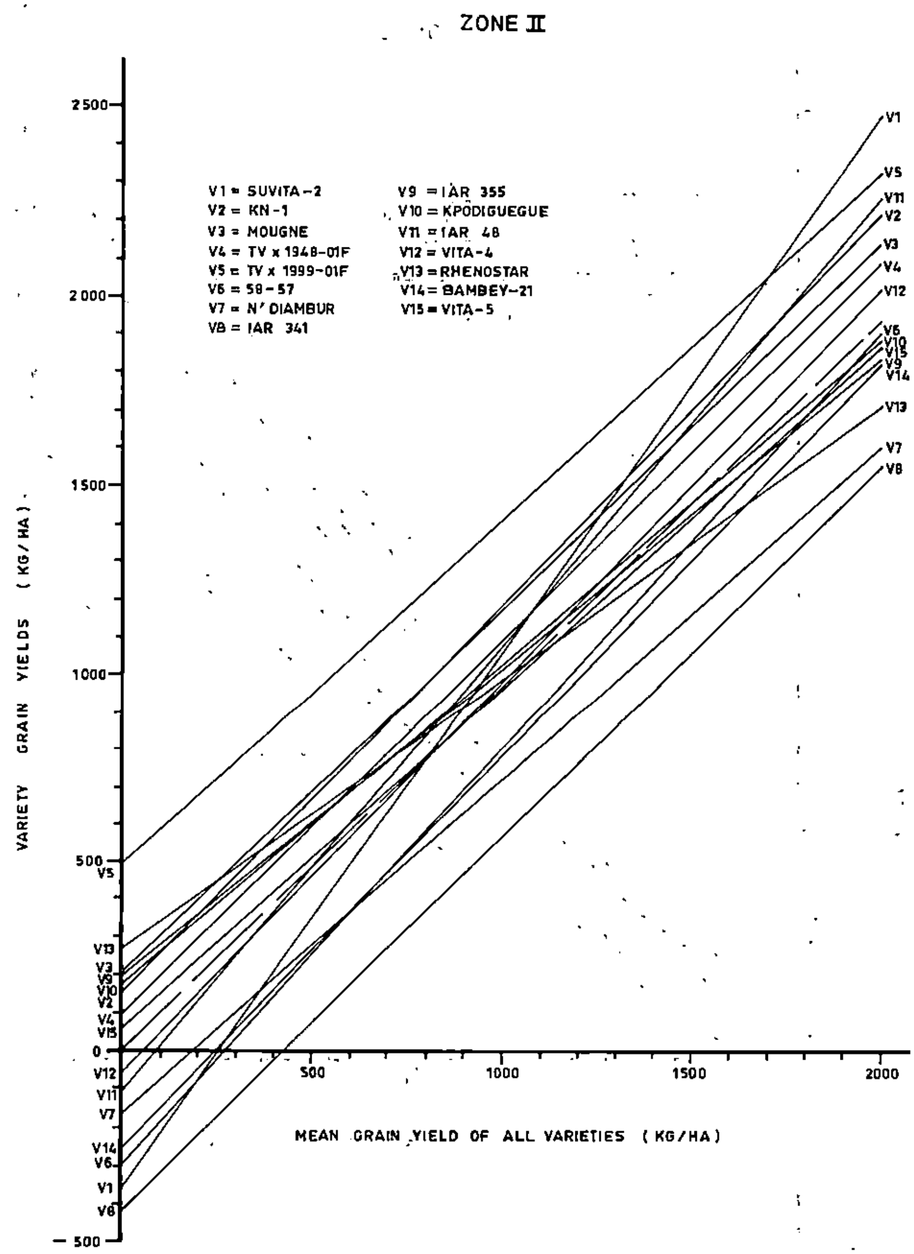

Figure 3 Grain yield response for 15 cowpea varieties to different environments within three Sudan Savanna rainfall locations, 1980-82.

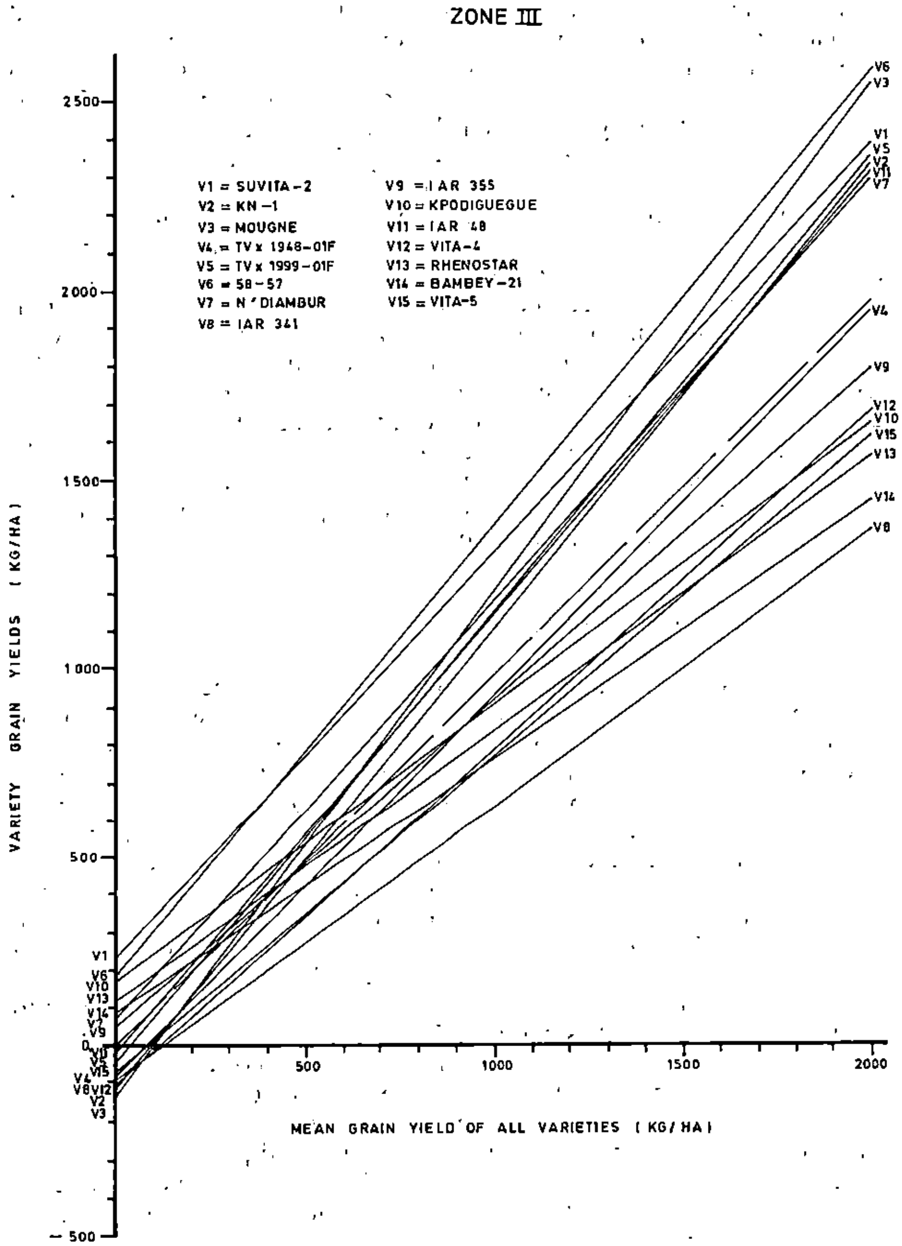

Figure 4 Grain yield response for 15 cowpea varieties to different environments within two Sahel Savanna rainfall locations, 1980-82.

Screening Approach and Strategy

Two types of approaches are generally considered for screening for drought resistance. One is the direct approach where selection for resistance is carried out under natural conditions for absolute performance i.e. yield, and growth characters. The other is the indirect approach where physiological or analytical characteristics are measured and correlated with drought (Seetharama *et al*, 1982). The direct approach was adopted in this work.

The breeding strategy was to grow the crop in the main growing season rather than screen it in the dry season under controlled irrigation. This is because in spite of a long dry season (November to May) where controlled irrigation is possible, screening is greatly influenced by variation in temperatures, which are relatively low from November to March and high from April to June until the rains start. To be more effective in the growing season, where the stress period is difficult to predict, the material is planted at different dates. The early generation material is planted in single rows alternated with the best adapted variety, whereas the advanced generation material is planted in four row plots replicated with a best variety or varieties as control. The final evaluation is based on yield. So far, this method has proved to be successful, and several varieties consistently performing well in the dry areas have been identified. However, the rate of success still depends to a great extent on time and frequency of drought stress. The efficiency of screening can be increased, at least theoretically, if some kind of rain-out shelters are used with supplementary irrigation. This will help in creating drought conditions when desired.

Characters Associated with Drought

For selection to be effective in any breeding program, the breeder should know which characters to look for. It should also be easy to identify or measure these characters. Several workers believe that since the rainy season is short in the dry areas, early maturing varieties with synchronous flowering should perform better in those places. But the environment in such areas, particularly in the Sahel, is quite complex, and early maturity *per se* in such areas is not sufficient. It must be associated in a plant type which has the capacity to recover from the drought stress and can flower profusely and set pods that reach maturity (IITA/SAFGRAD Annual Report, 1984). Varieties like SUVITA-2 and 58-57, which are medium in maturity and have the capability to recover from drought stress and produce higher number of flowers over a longer period of time, have been found to perform better than varieties like IT 82E-60, KVu 55 etc, which are early in maturity and produce less number of flowers over a shorter period of time (IITA Research Highlights, 1984). In addition, plant vigour measured as dry matter seems to be an important character. Studies have shown (Aggarwal and Haley, 1986) that dry matter was significantly and positively correlated with grain yield in the dry areas. The low dry matter producing varieties were rather early in maturity, thus supporting our earlier view that early maturity as such may not be a desirable trait in dry areas. Number of pods per plant was a desirable character. However, harvest index measured as ratio of plant weight to grain weight, was not satisfactory.

Breeding for Striga Resistance

Striga gesnerioides or witchweed is a serious problem in sevral cowpea producing areas of West Africa. The most seriously infested areas are in the semi-arid drought striken belts of Nigeria, Niger, Burkina Faso, Mali and Senegal. Therefore, varieties suitable for these areas should combine resistance to *Striga* and drought to make them more profitable. In serious *Striga* infestation, susceptible cowpea plants can be completely killed. The use of resistant varieties is the most convenient and easiest method for dealing with this problem. The IITA's program in Burkina Faso has therefore focussed attention on identifying cowpea varieties resistant to *Striga*. The program was started in 1981 and since then a considerable amount of progress has been made.

Striga Resistant Varieties

Two varieties, SUVITA-2 and 58-57, were first reported to be free from *Striga* infestation at Kamboinse, Burkina Faso in 1981 (IITA/SAFGRAD Annual Report, 1981) and since then this resistance has been subsequently confirmed and documented (Aggarwal *et al* 1984, Aggarwal *et al* 1986). In 1983, a systematic testing program was initiated in the region infested with *Striga*. Trials were conducted in Niger, Nigeria, Burkina Faso, Mali and other countries. The material tested in these trials included SUVITA-2, 58-57 and derivatives of crosses of SUVITA-2 with other promising varieties. Reaction of selected varieties to *Striga* is given in Table 6. The major findings were that SUVITA-2 and 58-57 maintained their high level of resistance in Burkina Faso, but were susceptible in Niger and Nigeria. SUVITA-2 was relatively resistant in Mali but 58-57 was susceptible. These varying results in different countries suggested the presence of different strains (populations) of biotypes of *S. gesnerioides*, an observation, later confirmed in collaborative experiments with Dr. C. Parker of the Weed Research Division (WRD), Oxford, England.

In spite of susceptibility of SUVITA-2 in Nigeria, some of the breeding lines derived from it have shown remarkable level of resistance in that country. Results received from IAR, Samaru showed KVx 30-183-3G and KVx 61-2 to be completely free from *Striga* in 1985 at Bakura, a heavily infested site in Northern Nigeria. Two other lines, KVx 30-403-1G and KVx 100-8, also appeared to be promising. The results from 1985 regional trial at Maradi in Niger have also shown that SUVITA-2 was resistant and KVx 30-166-3G, KVx 30-183-3G and KVx 100-2 were less infested (IITA/SAFGRAD Annual Report, 1985).

Combining Striga and Drought Resistance

Since *Striga* is more of a serious problem in the dry areas, it is important that varieties developed for such areas should also combine resistance to *Striga*. Fortunatelwy, SUVITA-2 which is resistant to *Striga* is also adapted to dry areas and is presently the best variety that combines these two characters. However, efforts are underway to develop new varieties. Crosses have been made and a selection KVx 61-74 developed from crosses between SUVITA-2 and TVx 3236, appears to be quite promising (IITA/SAFGRAD Annual Report, 1985).

Table 6 Reaction of different cowpea varieties to *Striga* strains (populations) found at different sites in four countries in West Africa.

Varieties	Per cent cowpea plants infested with Striga											
	Kamboinse, Burkina Faso			Kporo, Mali			Magaria, Niger			Baakura, Nigeria		
	1983	1984	1985	1983	1984	1985	1983	1984	1985	1983	1984	1985
KVx 30-166-3G	0.0	3.5	0.0	6.3	13.6	-	2.0	-	47.3	39.3	49.4	13.3
KVx 30-183-3G	0.0	1.0	0.0	0.0	0.0	-	3.0	-	27.1	19.0	51.0	2.7
58-57	1.0	-	-	19.3	-	-	44.4	-	-	37.3	-	-
SUVITA-2	0.0	0.0	0.0	3.3	17.8	-	5.0	-	44.7	19.3	51.3	4.6
Mougne(Susceptible)	87.3	33.7	39.3	28.1	32.4	-	45.8	-	76.4	44.7	79.6	42.0

Source: Data from the Regional Cowpea Striga Trial published in the IITA/SAFGRAD Annual Reports, 1983, 1984 and 1985, respectively.

Combining Resistance to Striga with other characters

In addition to resistance to drought, efforts have been made to combine the *Striga* resistance with other characters such as resistance to insect pests and diseases, high yield and good seed quality which are important in cowpea production in the semi-arid areas. Notable progress has been made to combine *Striga* and bruchid (a storage insect) resistance together with good seed quality characters (Aggarwal *et al*, 1986). Similarly, varieties have been developed which combine resistance to *Striga*, good seed quality, high yield and resistance to diseases. Examples are KVx 71-74, KVx 21-7, KVx 183-1, KVx 61-1 etc. (Aggarwal *et al* 1986 and IITA/SAFGRAD Annual Report, 1985). Limited quantity of seed of these varieties is available with the IITA/SAFGRAD Program in Burkina Faso.

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24 Cowpea Improvement and Production in the Semi-Arid Regions of Nigeria

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Introduction

Africa cannot provide its people with adequate food of the right quality and quantity without importation or aid from other continents partly due to the frequent occurrence of drought.

Drought can be defined, roughly, as a long period without rains at a time when they are normally expected. The distribution, duration and total amount determine the agricultural effectiveness of the rains. In some parts of Africa in some years, the rains hardly come when expected and when they do, they are of short duration and erratically distributed. Long spells without rains are not unknown.

Although the occurence of droughts cannot be prevented, some measures to reduce their effects whenever they occur can be adopted. One measure is to seed the cloud and create artificial rains. Another option is to provide supplementary irrigation to crops during the wet season whenever a dry spell occurs.

Crop breeders can also breed drought resistant high yielding short season varieties of the major food crops. Animal breeders should produce hardy breeds of animals that can grow rapidly on the available food and crop residue during the short period of rains and thereafter thrive and maintain their weights throughout the long dry season when feed and drinking water are in short supply.

This paper will discuss our experience in cowpea production and genetic improvements to overcome some of the constraints in the Sudan and northern Guinea Savanna, the main cowpea producing region of Nigeria.

Savanna Regions of Nigeria

According to Kowal and Knabe, 1972, six very distinct vegetation zones are recognized in Nigeria. These are the Sahel, Sudan, Northern Guinea, Southern Guinea, Forest and Coastal Swamps. The major factors responsible for these vegetation zones are the amount and intensity of the climatic parameters. Four of these zones, the Sahel, Sudan, northern Guinea and Southern Guinea, constitute the Savanna Regions of Nigeria. The Sudan and the adjacent portions of the northern Guinea are the most important zones for cowpea production in Nigeria. These two zones cover an area of about 400,000 km^2 within latitudes 10 and 13° North longitude 4 and 14° East.

The Place of Cowpea in the Nigerian Economy and in the Farming Systems of the Savanna Regions

Cowpea, *Vigna unguiculata*, is the most important grain legume consumed in all parts of Nigeria. It contributes about 57% of the toal proteins from legumes but only about 3% of the total protein intake (Anon 1971). The dry grains are for direct human consumption while the stems, leaves and the empty dry pods after shelling are very nutritive and additional sources of animal feed.

Cowpea production in Nigeria is concentrated in the Sudan and the adjacent parts of the northern Guinea Savanna accounting for over 75% of total production. These zones receive less than 1,000 mm of annual rainfall (Tables 1. and 2). Borno, Kano and Sokoto are the leading cowpea producing states in Nigeria. Familiar names such as Dan Borno (Brown beans) and Sokoto beans (white beans) are the preferred types of beans produced. There is a lot of interstate trade in cowpea between the major producing areas in the Savanna region and the southern parts of Nigeria.

Table 1 Monthly Rainfall Figures (mm) for Bakura from 1974 to 1985

Year	F.	M.	A.	M.	J.	J.	A.	S.	O.	Total
1974				7.8	58.8	146.2	318.8	135.2	10.8	677.6
1975			37.2	90.3	40.8	119.4	205.4	128.2	—	621.8
1976				64.0	166.0	82.4	214.6	72.4	152.7	752.1
1977				51.7	90.8	155.7	278.8	176.8	5.0	758.8
1978		6.7	38.7	51.7	143.9	230.4	150.6	167.8	3.4	793.2
1979			51.1	56.2	154.9	170.9	125.2	33.2	—	591.5
1980			—	126.0	139.2	226.5	196.0	94.9	—	782.6
1981			—	30.8	18.4	182.9	110.6	82.5	—	425.2
1982	3.4	—	0.2	59.9	72.4	134.1	246.8	101.1	33.9	651.8
1983	—	0.2	—	31.4	105.3	142.6	116.3	79.9	—	475.7
1984	—	—	—	57.5	140.7	51.9	56.4	84.3	10.5	401.3
1985		12.4	—	20.8	12.4	155.6	267.0	192.0	—	660.2

A very high percentage of the crop is intercropped with millet, sorghum and more recently with maize by small scale farmers. Another recent development is the cultivation of sole cowpea in large hectarage following the demonstration that chemical insect control in sole cropped cowpea is effective and profitable. Since most of the production is still in the hands of small scale farmers, reliable production statistics are hard to obtain. It is however estimated that more than 1.5 million hectares of land are under cowpea production yielding about 900,000 tonnes of grains (Anon 1974). Yield per hectare is very low.

Many factors militate against high yields and large scale production of cowpea in the main producing zones. Some of these factors include unreliable rainfall, the use by farmers of unimproved local varieties, insect pests, diseases and parasitic weeds.

Unreliable Rainfall

One of the major climatic factors affecting crop production in savanna region of Nigeria is the annual rainfall. The start, distribution, duration and total amount of the rains determine the time of planting, the length of the growing season and the type and varieties of crops to be grown.

An important climatic characteristic of the region is the existence of two distinct seasons – the dry and wet. The dry season lasts for more than seven months of the year, October to May. There is no agriculturally effective rain during this period. The wet season, on the other hand, lasts for about four months (May/June to September/October). The rainfall is monomodal. The onset is unpredictable and erratic from one year to another. For example at Bakura (Lat. 12.3° North and Long. 6° East) the first shower in 1981 came in May but in 1982 it came in February (Table 1). In general, the rain is "established" by June. July and August are usually the wettest months accounting for about half of the total rainfall.

The annual rainfall figures for Kano (Lat. 12.03° North and Long. 8.32° East) and Samaru (Lat. 11.11° North and Long. 7.38° East) are presented in Table 2 to illustrate the erratic annual rainfall pattern and its progressive decline.

Table 2 Annual rainfall (mm) at Kano and Samaru from 1973 to 1985

Year	Kano	Samaru
1973	539.8	974.1
1974	610.00	1115.9
1975	678.9	988.1
1976	669.1	1196.4
1977	733.3	745.5
1978	847.2	1148.9
1979	579.6	1193.7
1980	787.6	847.4
1981	560.4	1019.1
1982	637.6	768.5
1983	431.5	608.2
1984	507.3	888.0
1985	794.3	1051.8

Even when the rains are "established", there are often periods of five or more days of dry spells (Table 5). Such periods are critical to cowpea production if they occur immediately after germination or during flowering.

Local Unimproved Varieties

Most farmers still plant unimproved local varieties. These varieties are photosensitive, low yielding, spreading and long season. They flower about the end of September which coincides with the end of the rains and consequently there is very little moisture in the soil to sustain stable high grain yields. (Tables 5 & 6). Because of their spreading habit, most of the photosynthates are diverted to the production of vegetative parts and very little to grain formation thereby resulting in poor yield per area. Pods and flowers are hidden by the heavy foliage which makes it impossible for direct contact with insecticides for effective pest control and harvesting.

Insect Pests

Different parts of cowpea including the leaves, flowers, pods and dry grains are attacked by all kinds of insects in the field. In the Sudan and Guinea savanna, insects attacking the flowers and the pods are the most important and constitute the greatest hazard in cowpea production. Farmers are fully aware of the insect hazard associated with sole cropped cowpea, and cowpea is intercropped to reduce this problem. Through intercropping, farmers have been able to obtain some grain yields without chemical insect control.

Little has been achieved by breeding for resistance to the many insects which attack cowpeas at the post flowering stages. Some lines developed by the International Institute of Tropical Agriculture (IITA) Ibadan exhibit some level of resistance to thrips. This resistance is lost whenever thrips populations are high. Consequently, sole cropped cowpea must be protected with insecticides in order to obtain a good yield. So far, effective and economical chemical insect control measures have been developed and yields of more than 1.5 tonnes have been obtained with good insect control.

Parasitic Weeds

Two species of parasitic weeds (*Alectra vogelili* and *Striga gesneroides*) are known to parasitise cowpeas in the Sudan and Guinea savanna regions of Nigeria. *Striga* is much more serious in the Sudan and parts of the northern Guinea than *Alectra*. Cowpeas parasitised by these weeds are usually destroyed or the yield reduced to almost zero.

Cowpea Improvement

The Institute for Agricultural Research (IAR) Samaru and the International Institute of Tropical Agriculture (IITA) Ibadan are the main research institutes involved in cowpea improvement programmes in the Sudan and northern Guinea Savanna. Currently, the Institute for Agricultural Research conducts research on the agronomy, soil, pathology, entomolgy, weed science and genetic improvement of cowpea. The advances made on the genetic improvement of cowpea at the Institute for Agricultural Research, will be presented in this section.

Our cowpea breeding programme is aimed to producing improved cowpea varieties to correct most of the short comings of the local varieties and with seed qualities acceptable to the Nigerian consumer. Such qualities include large or medium seed size, white or brown seed coat colour and rough seed coat texture for rapid water imbibition to facilitate seed coat removal and short cooking time. High yielding medium maturing (75-90 days) cowpea varieties with resistance to some of the major cowpea diseases have been developed. The plant architecture has also been restructured. Rather than the spreading and leafy inefficient factory of most of the local varieties, the improved types are upright with their pods borne above the crop canopy. Upright plants with pods above the canopy are easier to treat with pesticides for insect pest control on flowers and pods and are also easier to harvest.

The improved varieties are more efficient in grain production and they exhibit less fluctuation in yield from one year to another (Table 3). There is reduced complete crop failure from one location to another (Table 4). Because they are medium in maturity, many of the improved varieties flower before the end of the rains. There is therefore adequate moisture in the soil to sustain a high yield. The local long season photosensitive varieties, on the other hand, flower towards the end of the rains when the day length is appropriate. In many years there is little moisture in the soil to sustain a high yield resulting sometimes in complete crop failure. The yields of the local varieties therefore exhibit a high degree of fluctuation from one year to another depending on the amount of moisture in the soil.

Table 3 Yields (Kg/ha) of IAR 341 and a local variety at Tumu (Bauchi State, Nigeria)

Line	1978	1982	Yield fluctuation between years
IAR 341	2299	2098	201
Local	212	1839	1627

Tables 5 and 6 illustrate the fifty percent flowering dates of an improved variety IAR 341 and a local variety at Tumu in 1978 and 1982 in relation to the rains and moisture availability. The improved variety, IAR 341, flowered in both years towards the end of August thereby making use of subsequent rains and the moisture in the soil. The local variety reached fifty percent flowering stage in October 1978 after which only 69.1 mm of rain fell. There were also long spells without rain before and after flowering. In 1982 there was no rain after the local reached fifty percent flowering stage. However the days before it attained fifty percent flowering had better rainfall distribution and hence more moisture in the soil. This could explain the better yield performances of the local in 1982. The fluctuation in yield of the local in the two years can be explained therefore by the greater moisture stress before and after flowering in 1978 than 1982.

Because the local varieties are long season and photosensitive they are more likely to fail completely in many locations in any given year while the improved varieties, under the same management conditions as the local, give more or less stable yields from one year to another (Table 3). Leleji (1980) explained the fluctuations or complete failures of most local varieties of cowpeas in the Sudan and Guinea savanna in terms of moisture availability. He noted that long season and photosensitive local varieties fail to reach physiological maturity before the soil moisture is depleted and therefore are not likely to produce their maximum genetic yield. They are likely to have a large number of shrivelled or unfilled pods and grains.

Poor management could be a factor in these multilocational trials but the local varieties failed completely in four out of the seven locations. This is in contrast with a recently released IAR variety SVu 48 which came first or second in six of the seven locations with a yield of more than 1.5 tonnes per hectare in two locations.

Parasitic Weeds

Striga gesneroides, a parasitic weed of cowpea, is now a serious threat to cowpea production in the Sudan and northern Guinea Savanna. The Institute for Agricultural Research has in conjunction with SAFGRAD in Burkina Faso been looking for sources of genetic resistance. A number of lines have been identified and further tests are being carried on to confirm their resistance. Yields in kg/ha in a *Striga* affected field at Bakura in 1984 and 1985 are presented in Table 7.

Table 4 Yields of improved cowpeas (kg/ha) compared with different local varieties in seven locations in Nigerian Sudan and Guinea Savanna in 1985

Bunza		Deba		Fika		Gamawa		Maiduguri		Misau		Tumu	
Line	Yield	Line	Yield	Line	Yield	Line	Yield	Line	Yield	Line	Yield	Line	Yield
*SV-2	1900	SVu48	898	SVu48	781	**KVX	481	SVu48	1458	*SV-2	1067	SVu48	1913
SVu48	1655	*SV-2	846	*SV-2	585	*SV-2	351	180-4	1183	SVu48	690	341	1796
176B	1425	176B	781	176B	364	SVu48	325	*SV-2	1171	176B	416	*SV-2	1614
355	1248	341	729	335	299	180-4	208	81-40	1093	335	351	176B	1523
335	1171	72	703	355	273	176B	156	335	1067	81-40	338	180-4	1328
341	911	335	624	341	130	341	143	Local	1028	180-4	273	72	1171
81-40	820	81-40	611	81-40	104	72	117	355	950	355	260	81-40	1145
72	722	**KVX	520	72	52	81-40	117	341	781	341	234	Local	976
180-4	494	180-4	429	180-4	13	335	65	72	663	72	195	355	950
Local	Failed	Local	390	Local	Failed	Local	Failed	176B	598	Local	Failed		

* Suvita-2.
** KVX30-403-1G.

Table 5 Rainfall (mm) at Tumu June/November 1978 and Fifty percent Flowering of IAR 341 and a Local Variety

Date	June	July	August	September	October	November
1	—	—	18.28	19.56	—	7.62
2	—	25.40	1.27	—	17.78	—
3	12.70	—	—	—	—	—
4	—	41.91	—	6.85	—	—
5	—	—	—	—	—	—
6	5.58	—	—	12.19	—	—
7	—	—	—	—	—	—
8	1.77	11.68	—	2.03	—	—
9	15.74	—	27.69	—	—	—
10	—	8.63	—	—	—	—
11	—	—	—	—	—	—
12	—	—	—	—	—	—
13	3.55	25.65	—	27.43	b	—
14	TR	—	—	—	—	—
15	—	—	—	—	—	—
16	32.5	6.35	4.82	—	19.81	—
17	—	7.87	TR	30.98	11.68	—
18	—	33.27	32.00	8.89	—	—
19	3.81	—	—	12.19	—	—
20	—	—	21.33	—	—	—
21	—	—	21.50	—	—	—
22	—	—	—	TR	—	—
23	27.68	—	—	—	—	—
24	—	3.8	TR	3.55	—	—
25	—	33.02	—	TR	19.56	—
26	—	1.27	—[a]	—	—	—
27	—	—	8.13	—	—	—
28	TR	—	—[a]	—	2.54	—
29	13.97	—	—	—	7.87	—
30	—	—	2.54	—	—	—
31	—	—	—[a]	—	—	—
Total	117.8	198.8	135.3	123.69	79.24	7.62

50% Flowering dates: a. = 341 b. = Local

The yields of these resistant lines are very encouraging when compared with the susceptible lines. Lines KVX30-183-1G, KVX30-166-3G and KVX100-2, in addition to the high yields resulting from resistance to *Striga*, have large attractive seeds.

Drought Resistance

In the Sudan and Guinea savanna, cowpea should be planted in late June to middle July when the rains should have become well established. This gives the crop ample time to grow, develop and produce mould-free grains since the grains mature after the rains are over. During the period of growth and development dry spells of five or more consecutive days can occur and this can affect the performance of the varieties. Short and medium duration varieties have been successfully bred but short or medium duration varieties

Table 6 Rainfall (mm) at Tumu between August and November 1982 and Fifty Percent Flowering Dates of IAE 341 and a local variety

Date	August	September	October	November
1		66.6		
2			8.5	
3		12.6		
4		10	6.0	
5				
6			1.5	
7				
8	20.0	21.0	11.0	
9	4.0		22.5	
10	62.0			
11		4.5	7.5	
12				
13	15.0		4.0	
14		5.6		
15	4.2		b	
16				
17				
18		1.6		
19	10.0			
20	5.0	5.0		
21	5.0			
22	2.5	10.0		
23	1.0			
24				
25				
26	a	5.3		
27				
28				
29		16.6		
30	5.5[a]			
31				
Total	134.2	159.3	61.0	

50% flowering dates: a = 341 b = Local

Table 7 Yields (Kg/ha) of Seven *Striga* resistant lines at Bakura in 1984 and 1985

	Yield	
	1984	1985
KVS30-183-1G	1805	3633
KVX30-166-3G	1402	3276
Suvita-2	1902	3249
KVX61-2	1583	3183
KVX100-2	1582	2883
KVX61-74	—	2883
KVX100-1	1374	2883
Susceptible	527	41

alone cannot protect a variety from the adverse effects of drought. The effects of a 6 day dry spell on a 60 day cowpea is much more devastating than the same on a 90 day cowpea. The former is more likely to be a relatively small plant with correspondingly small root system which may not be efficient in tapping the soil moisture. Drought resistance, ability to withstand short dry spells, must be incorporated in varieties intended for cultivation in the drought prone zones.

The Institute for Agricultural Research in conjunction with SAFGRAD has conducted trials since 1983 to identify drought resistant lines. In 1983 when there was drought attack by *Striga* and virus diseases was severe. In 1984, *Striga* made any assessment impossible. In 1985, drought reaction could not be assessed because there were no periods of dry spells long enough to distinguish between varieties.

Released Improved Varieties

The Institute for Agricultural Research has tested extensively a number of cowpea lines throughout the Guinea savanna. Based on their excellent performances compared with local checks, the Institute has recommended some high yielding medium duration cowpea varieties described in Table 8 for cultivation in the Sudan and Guinea savanna.

Table 8 Improved Cowpea Varieties Released for Production in the Sudan and Guinea Savanna

Variety	Seed Coat Colour	Seed Coat Texture	Seed Size	Potential Yield (Kg/ha)
IAR 341	Rusty white	Rough	Medium	1,000-2,000
IAR 176B	White	Rough	Medium/Large	1,000-2,000
IAR 355	Dark brown	Rough	Medium	1,000-1,500
IR 353	Dark brown	Rough	Medium	1,000-1,500
IAR 335	Dark brown	Rough	Medium	1,000-1,500
SVu 48	Light brown	Rough	Large	1,500-2,500
Kano 1696*	White	Rough	Extra large	1,000-1,500
Ife Brown**	Brown	Rough	Medium	1,000-2,500
TVX 3236***	Rusty cream	Rough	Small/Medium	1,500-2,500
IT 60***	White	Rough	Large	800-1,000

* An improved, photosensitive spreading local variety. Recommended for the southern parts of the Guinea Savanna.
** Bred at the University of Ife.
*** Bred and released by IITA.

A new set of promising lines bred in the Institute and other research Institutes are being evaluated in the All Nigerian Coordinated Cowpea improvement programme.

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25 Responses of Cowpeas to High Soil Temperatures and Drought

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Abstract Experiments were conducted in the field (in 1984 and 1985) and in potculture during dry season of 1985 in the Sudan Savanna, in Burkina Faso, to study the effects of drought (D) and high soil temperature (HST) on cowpeas [*Vigna unguiculata* (L.) Walp.]. In field experiments, low soil temperatures (LST) were induced by covering soil with straw mulch. In potculture LST and HST were induced by covering pots with aluminum foil and polyethylene sheets, respectively. Three ten-days-moisture stress treatments, beginning 15 and 38 days after planting and slightly after flowering, and a no moisture stress treatment were used in potculutre. The 1984 and 1985 crop seasons had a poorly and a well distributed (except towards its end) sub-normal rainfall, respectively. Supra-optimal air (effective day and night temperatures above 33 and 26°C, respectively) and soil (temperatures above 40°C at 5 cm depth in midafternoon) temperatures occured in both field and potculture experiments during dry spells. Different soil moisture regimes were induced in the 1985 field experiment by use of 2 dates of planting and by planting on flat, tied ridge and mulched plots.

Straw mulch and aluminum foil reduced soil temperatures markedly (down to 8°C difference) as compared to bare soil and polyethylene sheets, only during midafternoon hours, during dry spells. Their temperatures never exceeded 40°C. Temperatures of tied ridge plots were intermediate between those of bare flat and mulched plots. HST, in potculture, increased root dry weight, but reduced total water consumption and shoot dry weight of cowpeas. This implied that it had an adverse effect on transpiration, photosynthesis and overall plant growth and development. Thus it impeded the growth of cowpeas from the seedling to the maturity stages; delayed flower bud formation and flowering (as a consequence of flower bud abscission), but had a little effect on maturity; and reduced number of branches and flowers per plant and seed yield (SY) in the 1984 field and potculture experiments, which experienced protracted dry spells.

Cultivar differences in resistance to HST were observed in potculture. HST prevented HST-susceptible cultivars from responding to moisture stress treatments. Only moisture stress (MS's) in the reproductive growth stages (RGS's) adversely affected SY of HST-resistant cultivar in potculture. In the 1985 field experiment, MS's and HST in the RGS's had no effect on SY of the HST-resistant cultivar, but significantly reduced those of the two HST-susceptible cultivars and all unmulched plots in the second compared to the first dates of planting. Flat, tied ridge and mulched plots did not significantly differ from one another at both dates of planting in 1985.

Resistance to HST thus appeared to be a prerequisite to better performance under HST and D conditions of semi-arid West Africa.

Introduction

In semi-arid West Africa, drought is always associated with a high solar radiation load. This results in high air and soil temperatures (T's). Air and soil (read at 5 cm soil depth) T's may increase markedly above, 30 and 40°C respectively as dry spells progress. Plants under those conditions may suffer of either drought, high air or soil temperatures or a combination of any two or all of the three climatic factors.

High air temperatures, particularly a combination of effective day and night temperatures, respectively, above 33°C and 26°C have been reported to adversely affect cowpea seed yield, if they occur during flowering even with well watered cowpea crop (Turk et al 1980, Warrag and Hall 1983). The observed yield reduction was mainly due to male sterility induced by high day and night temperatures and to embryo abortion induced by high day temperatures (Warrag and Hall, 1983). High soil temperatures do not appear to affect flower abscission if they were not combined with high night temperatures (Warrag and Hall, 1983).

Roots of plants biosynthesize growth regulators: cytokinin and gibberelic acid (Salisbury and Ross 1978, Skene 1975). Although these two hormones are also produced in developing young organs, roots appear to be their main source; they play a major role in shoot growth and development (Salisbury and Ross 1978). Soil temperatures above 40°C, which are close to physiological limits 45-50°C (Huber 1935), may increase respiratory processes and deplete available photosynthates at the expense of crucial biosynthesis (Hellmers and Warrington 1982). They may, thus adversely affect shoot growth and development and, consequently, seed yield.

Since drought and its associated high solar radiation load may occur any time in Sudan Savanna and the Sahel agroclimatic zones of West-Africa, it is therefore, imperative to investigate the effect of reduced soil temperatures on cowpea throughout a crop season. This may provide crucial information, which, through genetic and/or environmental manipulations, could lead to the development of new production technologies that can reduce severe yield losses during dry spells. Field experiments were therefore conducted in 1984 and 1985 and a potculture experiment, in 1985, to achieve this objective.

Materials and Methods

Field experiments

The 1984 experiment

Cultivar SUVITA-2 was tested at Loumbila in a factorial experiment consisting of two levels of soil tillage (viz. zero-tillage with *in-situ* mulch and Oxen ploughing) and three levels of rock phosphatic fertilizer, Burkina Phosphate (27% of P_2O_5), with low solubility. The three levels of phosphatic fertilizer used were: 0, 100 and 200 kg/ha of P_2O_5. The experimental field was under a *Crotalaria* cover crop for one year. *Crotalaria* plants were cut in June 1984 to leave 10 cm height stubles. In plots receiving zero-tillage with *in-situ* mulch, stubles were killed with the herbicide "paraquat" and residues left on the soil as mulch; whereas they were ploughed-under in plots receiving conventional tillage. The phosphatic fertilizer was broadcast in all plots receiving that treatment, but was ploughed-under prior to planting only in plots receiving conventional tillage.

Cowpea plants were sown using spacings of 0.75 m between rows and 0.20 m between hills within each row. Two seeds were sown at 5 cm depth and thinned to one plant per hill fifteen days after sowing. Plot size was six rows, 6 m long. Plots were kept free of weeds by hand hoeing throughout the crop season. Flat seedbed plots were scarified whenever it was necessary to destroy the crust and improve soil water infiltration. Cowpea plants were sprayed with insecticides (viz. Nuvacron, Decis and Thiodan) four times during the crop season. The experiment was sown on 18 July and harvesting completed on 12 October 1984. The experimental design used was 2 x 3 factorial with randomized complete blocks replicated five times.

Flower bud formation (FBD), flowering (FD) and maturity (M) dates were determined as the date when 50% of plants per plot had, respectively, the first flower bud clearly visible, the first flower open and pods mature. At 50% podding, 3 plants were dug out. Roots were separated from the shoot and cleaned with water; nodules were separated from roots. Numbers of branches (BN) per shoot were counted; the length of the main stem (SL) and the longest branch (BL) were measured. Roots, nodules and shoots were separately dried in an oven at 70°C for 72 hours to determine their dry weight. Pods were harvested as they matured in three central rows, 6 m long, leaving 50 cm at each end; they were air dried to constant moisture and threshed. Dry grains were weighed precisely.

Cultivar SUVITA-2 was used because of its known resistance to drought and high heat.

A total of 475.7 mm rainfall (59.5% of long term average) poorly distributed during the crop season (Fig. 1) was received in 1984. This resulted in effective shelter air night and day temperatures above 25°C and 30°C respectively, during the major part of the crop season, with high values being reached during dry spells (Fig. 1). Effective night and day temperatures were calculated from the mean of the daily mean, and daily minimum and maximum temperatures, respectively. Soil temperatures at 5 cm depth were monitored from 27 August to 4 September. The bulb of mercury thermometers was placed at 5 cm depth, in a central row, half way between two consecutive hills. The soil was disturbed to minimum; and the aerial part of the thermometer was covered with aluminum foil to prevent direct absorption of solar radiation. Temperature readings were taken daily at 9:00, 12:00 hrs and 15:00 hrs in four mulched and four bare soil plots chosen at random. The average temperatures for mulched and bare soil plot at each observation hour is shown in Fig. 2. Soil temperature differences between bare and mulched soil plots were small during morning hours. They, however increased to 8°C during noon and midafternoon hours, particularly as dry spell progressed. Mulched plots maintained soil temperatures relatively low and below 40°C compared to bare soil plots.

Soil moisture content was monitored on 11 August and 28 October after, 8 and 10 day dry spells respectively. Soil cores were taken in each plot with a soil auger from 0-10 cm and 11-30 cm upper soil layers. They were immediately placed in air tight aluminum boxes. After the fresh weight was accurately determined, they were dried in an oven with forced air at 105°C for 72 hours. Soil moisture content was expressed as mm of water (after adjustment taking into account soil moisture content in percentage of dry soil and soil bulk density within each sampled soil layer) in 10 and 20 cm of, 0-10 and 11-30 cm upper soil layers respectively, as shown on Table 1. Mulched plots maintained a soil moisture content significantly higher than bare flat plots in both soil layers at both sampling dates.

The 1985 experiments

Three cultivars (viz. SUVITA-2, TN 88-63 and KN-1) of known drought and heat resistance characteristics were tested on two dates, 27 July and

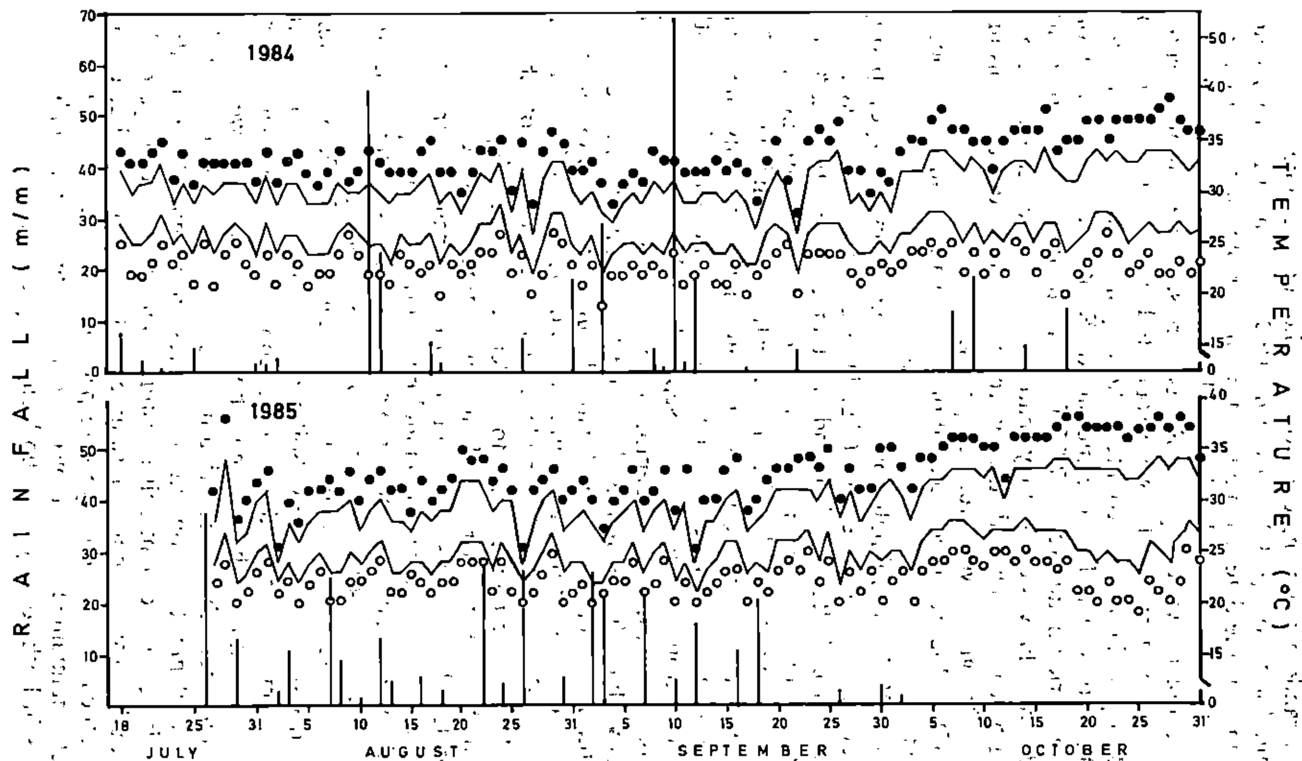

Figure 1 Rainfall and shelter air temperatures: daily maximum (●), daily minimum (○) and effective day and night temperatures, calculated from the mean of the daily mean and daily maximum and minimum, respectively, at Loumbila/Ouagadougou, Burkina Faso, 1984 and 1985.

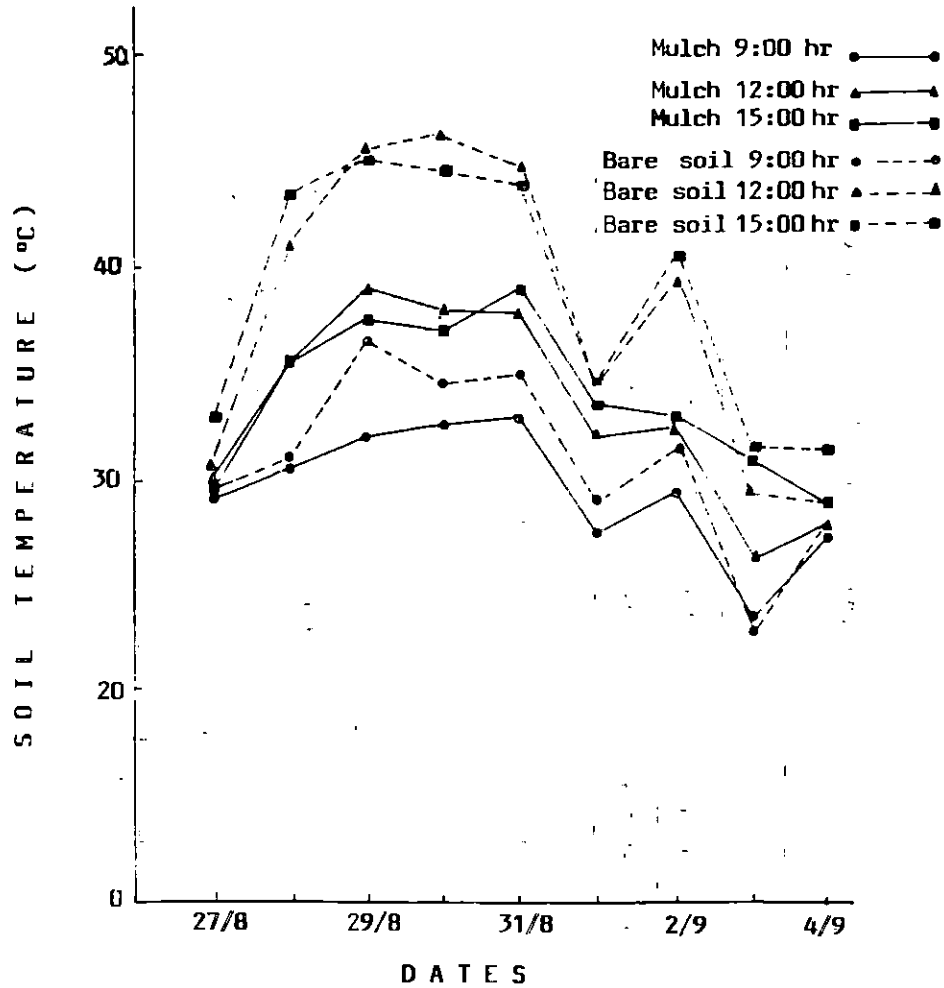

Figure 2 Soil temperature monitored at 5 cm soil depth in late August to early September, Loumbila, Burkina Faso, 1984. (The soil t°c monitoring was initiated after a 6.7 mm rainfall on 26/8; a 18.0 mm and 29.0 m rainfall-was received on the nights of 31/8 and 2/9, respectively, which explains soil t°c drop the following day).

8 August) and four seedbed preparation methods, viz. planting on flat, planting on flat converted to tied ridges 3 weeks after planting (WAP), planting on tied ridges and planting on flat mulched plots. SUVITA-2 and TN 88-63 are drought and high heat resistant cultivars; whereas KN-1 is drought and high heat susceptible. The experimental field was conventionally tilled to 25 cm soil depth prior to applying seedbed preparation treatments. Mulched plots received 40 kg (or equivalent of 14.8 T/ha) of *Crotalaria* crop residues. The two dates of planting and seedbed preparation treatments were used to induce different soil moisture and temperature regimès. All plots received the equivalent of 50 kg/ha of P_2O_5 from single super phosphate (18%), which was broadcast and plowed under prior to planting. The experimental design used was a split plot with dates of planting as main treatments and the combination of 3 cultivars and 4 seedbed preparation methods as subtreatments. The experiment was replicated 4 times. All agronomic practices used and data collected were

Table 1 Soil moisture content within 0-10 cm and 11-30 cm (in 1984), and 0-30 cm and 31-45 cm (in 1985) in upper soil layers at Loumbila/Ouagadougou, Burkina Faso.

Soil Managements	1984*				1985							
	11 August		28 October		10 September		20 September		30 September		8 October	
	0-10 cm	11-30 cm	0-10 cm	11-30 cm	0-30 cm	31-45 cm	0-30 cm	31-45 cm	0-30 cm	31-45 cm	0-30 cm	31-45 cm
						m/m						
– Flat beds	6.5 b	15.8 b	6.0 b	11.7 b	31 b	19 c	30 c	19 b	13 b	10 a	13 a	10 a
– Flat beds converted to tied ridges 3 weeks after planting	—	—	—	—	43 a	25 b	42 a	26 a	14 b	11 a	13 a	9 a
– Tied ridge beds	—	—	—	—	47 a	31 a	47 a	26 a	18 a	13 a	12 a	9 a
– Mulched beds	8.5 a	21.0 a	7.8 a	15.6 a	45 a	28 ab	44 a	24 a	18 a	12 a	14 a	10 a
LSD (5%)	1.8	4.6	0.7	2.7	4	3	7	4	3	NS	NS	NS
CV (%)	20	30	17	23	19	22	29	31	36	46	27	25

* Soil moisture contents on 11 August and 28 October 1984 were determined after, respectively, 8 and 10 day dry spells.
Mean followed by the same letter are not statistically different at 5% probability level.

similar to the 1984 field experiment, except that plants were uprooted at 50% maturity. Nodule (NDW), root (RDW) and shoot (SDW) dry weights; BN; SL; and BL were determined at that growth stage.

A total of 519 mm rainfall (64.9% of the long term average) well distributed during the crop season, except towards September and in October, was received in 1985 (Fig. 1). This resulted in effective air night and day temperatures, below 25°C and 30°C respectively, during most of the crop season except towards its end (Fig. 1). Soil temperatures, monitored at 5 cm depth from 16 September to 8 October showed small differences between flat, tied ridge and mulched plots during morning and midafternoon hours, as long as it was raining (Fig. 3). As soon as a dry spell established itself after 24 September, great temperature differences occured, in midafternoon, between flat and mulched plots; the temperatures of tied ridge plots were intermediate between those of the former two treatments (Fig. 3).

Soil moisture content within 0-30 cm and 31-45 cm upper soil layers was monitored at 10 day intervals from 10 September to 8 October 1985 (Table 1). Flat beds maintained a soil moisture content, in both soil layers, significantly lower than that of the other three soil management treatments, except on 30 September and 8 October. On 30 September, they maintained a soil moisture content, in 0-30 cm soil layer, similar to that of flat beds converted to tied ridges 3 WAP. In 31-45 cm soil layer, on 30 September, and both soil layers, on 8 October, there were no significant differences between soil water content of the soil management treatments. Except for the 31-45 cm soil layer, on 10 September, and 0-30 cm soil layer, on 30 September, soil moisture contents of flat beds converted to tied ridges 3 WAP, tied ridge beds and mulched beds did not differ significantly in both soil layers and at all sampling dates. Soil moisture content at the late two sampling dates were relatively low compared to those at the two early dates (Table 1). This suggested that soil moisture stress developed sometime around 30 September. Since cowpea reached 50% maturity between 27 September and 2 October, for the first date of planting, and between 6 and 13 October, for the second date of planting, the first cowpea crop suffered less moisture stress compared to the second.

Potculture experiment

The three cultivars used in the 1985 field experiment were tested at two soil temperatures and four moisture regimes. The experiment was conducted in potculture in open air. Pots were 10 litre plastic buckets. They were filled with 7 kg of dry sand and 2 kg of dried animal manure, making a total of 9 kg of solid soil substrate. Soil water field capacity was determined to equal 2.5ℓ per pot. (Perforated pots filled with a mixture of sand and animal manure were well watered and weighed 24 hours after excess of moisture had percolated, to determine soil water field capacity.) The soil temperature regimes consisted of high and low temperatures. The high soil temperature (HST) was induced by covering pots with a transparent polyethylene (plastic) sheet. The low soil temperature (LST) was induced by covering pots with aluminum foil. Pots were covered with either aluminum foil or plastic sheet 3 days after the emergence of seedlings. The soil moisture stresses were induced by with-holding moisture supply to pots for ten days beginning 15 and 38 days after planting (DAP) and slightly after flowering. The check treatment (no moisture stress) was watered to field capacity as needed throughout the growth cycle. Each pot was weighed daily to ensure

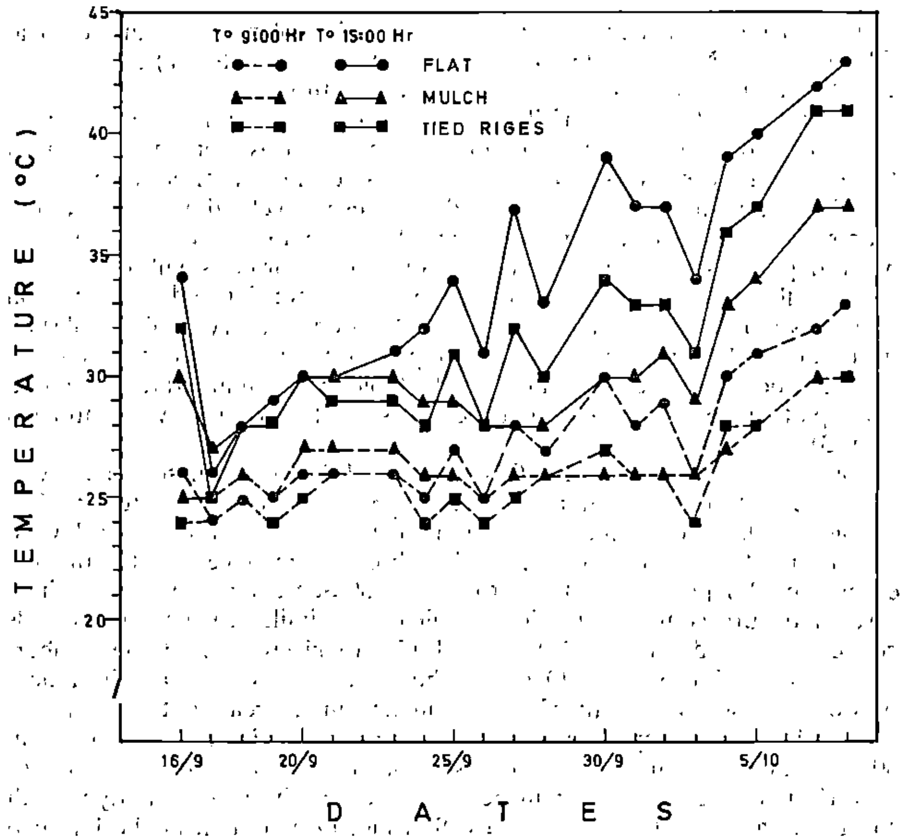

Figure 3. Soil temperatures at 5 cm depth read at 9:00 Hr and 15:00 Hr from September 16 to October 5, 1985 at Loumbila/Ouagadougou, Burkina Faso, 1985

that it received its appropriate treatment. Moisture supplied to each pot was recorded throughout the crop season and total water consumed was calculated at the end of the crop season. Since soil water evaporation was reduced to minimum by plastic sheets and aluminum foil, the water consumed at each pot corresponded mostly to cowpea transpiration at that pot.

Cowpea was planted at two seeds per hill and two hills per pot on April 15, 1985. They were thinned to one plant per hill 15 DAP. Seedlings, so harvested, were dried in an oven at 70°C with forced air for 72 hours and their dry weight precisely weighed.

The experimental design used was randomized complete blocks replicated three times. Cowpea plants were sprayed weekly with insecticides beginning with flower bud formation of the earliest cultivars. Data, similar to those collected for the 1985 field experiment was recorded, except that nodules were rated on a 1 to 5 scale (with 1 = no nodule and 5 = abundant nodules) and SDW did not include seed and husk dry weights.

Air temperatures during the crop season are shown in Fig. 4. Effective night and day temperatures fluctuated around 30 and 35°C, respectively, from 15 April to June, when they started declining; then around 25 and 30°C, after 15 June. Soil temperatures monitored at 5 cm depth, from June 1st to July 3rd, showed small differences between aluminum foil and polyethylene sheet covered pots during morning hours, but great differences (up to 6°C), during midafternoon hours (Fig. 5). Differences were particularly great from June 1st to 10, before rains started. Soil temperatures in aluminum foil covered plots remained equal to or lower than 40°C during the hotest monitored period. The experiment was completely harvested in early July, 1985.

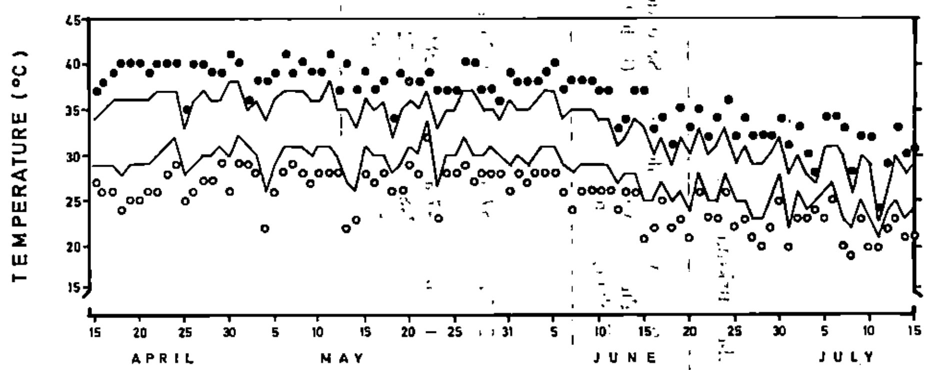

Figure 4 Shelter air temperatures, including daily maximum (●), daily minimum (○), and effective day and night temperatures, calculated from the mean of daily mean, and daily maximum and minimum, respectively, at Kamboinse/Ouagadougou, Burkina Faso, 1985.

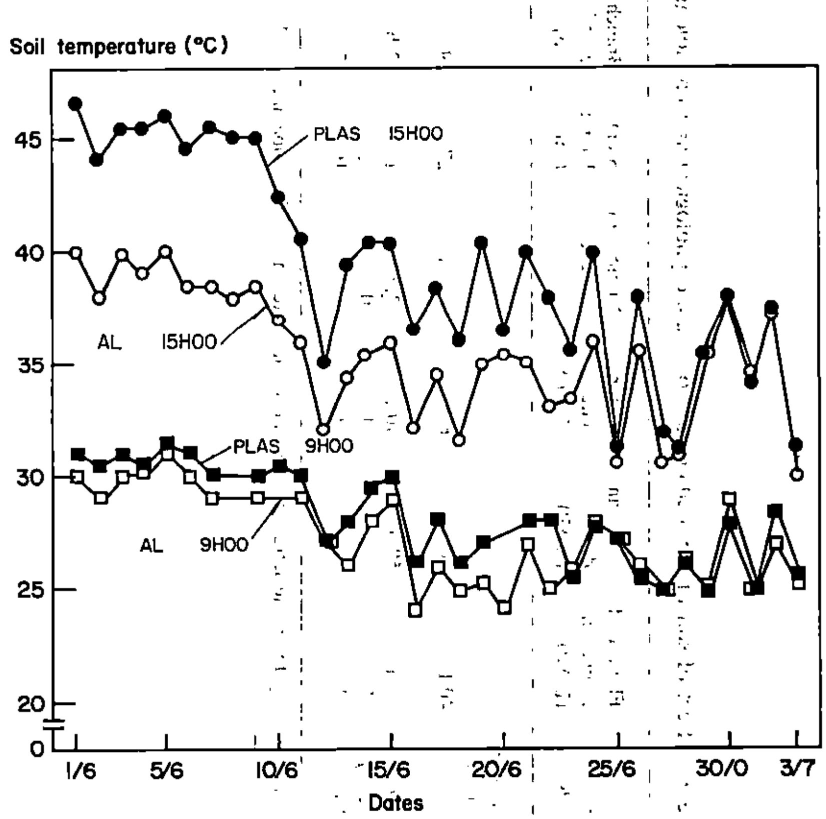

Figure 5 Soil temperatures at 5-cm depth in pot culture, Kamboinse (Ouagadougou) Burkina Faso, 1985.

Table 2 Effect of soil tillage methods on cowpea morphological and physiological traits, Loumbila, Burkina Faso, 1984.

Tillage methods	Floral bud formation (DAP)	Flowering dates (DAP)	Maturity dates (DAP)	Number of branches	Stem length (cm)	Branch length (cm)	Shoot dry weight (G/plant)	Root dry weight (G/plant)	Nodule dry weight (mg)	Seed yield (kg/ha)
Zero-tillage with *in-situ* mulch	40 b	46 b	69 a	4.3 a	27 a	39 a	33 a	2.05 a	57 a	1026 a
Oxen plowing	43 a	50 a	70 a	3.7 b	17 b	13 b	15 b	1.52 b	47 a	386 b
LSD (5%)	1	1	1	0.4	3	8	5	0.4	NS	272
CV (%)	3	3	1	13	16	37	26	26	86	45

Means followed by the same letter are not statistically different at 5% probability level.

Results

Field experiments

The 1984 experiment

Cowpea did not respond to P_2O_5 levels, but to soil tillage methods. FBD and FD occured much earlier in mulched than in bare soil plots; but all plots matured at the same time (Table 2). Thus, the reproductive growth duration was much greater in mulched than bare soil plots. Also mulching induced great RDW, long SL and BL and several BN as compared to bare soil. All these resulted in greater SDW and SY for mulched compared to bare soil plots (Table 2).

Table 3 Flower bud formation and flowering dates; branch length; branch number and root dry weight of cowpeas at Loumbila/Ouagadougou, Burkina Faso, 1985.

Cultivars	Flower bud formation dates (DAP)	Flowering date (DAP)	Branch number (n°/pl)	Branch length (cm)	Root dry weight (gr/pl)
SUVITA-2	34 a	46 a	5.8 b	101 b	5.6 b
TN 88-63	31 b	42 c	6.8 a	125 a	3.6 c
KN1	34 a	44 b	5.7 b	116 ab	8.4 a
LSD (5%)	0.3	1	0.5	16	1
CV (%)	2	3	16	28	31

Means followed by the same letter are not statistically different at 5% probability level.

The 1985 experiment

FBD and FD were significantly affected by cultivars (Table 3). TN 88-63 formed flower buds and flowered earlier than the two other cultivars, which did not differ from one another except for FD. SUVITA-2 flowered later than KN-1. Number of days from planting to maturity (M) was significantly affected by the dates of planting/cultivars interaction and by managements (Tables 4, 5). M of SUVITA-2 and KN-1 were unaffected by dates of planting; whereas that of TN 88-63 was reduced by 4 days in late planting (Table 4). Planting on flat beds significantly reduced M by 2 days compared to the other three soil managements regardless of date of planting and cultivars. SL was significantly affected by the cultivars/soil management interaction; whereas BN and BL were significantly affected by cultivars only (Tables 3, 5). SL of SUVITA-2 was the shortest on flat-beds and flat-beds at planting converted to tied ridges 3 WAP; it increased significantly to become similar to that of TN 88-63 and/or greater than that of KN-1 on tied ridge and mulched beds. SL of TN 88-63 and KN-1 were unaffected by soil managements, except for KN-1 on mulched beds (Table 5). TN 88-63 produced more BN than SUVITA-2 and KN-1. It had greater BL than SUVITA-2; KN-1 was intermediate between them (Table 3). SDW of TN 88-63 and KN-1 were unaffected by soil managements; whereas that of SUVITA-2 increased significantly as more soil water was made available by soil management treatments (Tables 1, 5). SUVITA-2 (at low soil available moisture) and TN 88-63 (at high soil available moisture) tended to produce less SDW compared to the other two cultivars. KN-1 had the greatest

Table 4 Maturity dates and seed yield as affected by dates/cultivars interactions and seed yield of cowpeas as affected by dates/managements interaction at Loumbila/Ouagadougou, Burkina Faso, 1985.

Dates	Maturity dates			Seed yield						
	Cultivars			Cultivars			Soil managements			
	SUVITA-2	TN88-63	KN-1	SUVITA-2	TN88-63	KN-1	Flat	Flat tied ridges	Tied ridges	Mulch
		DAP			kg/ha			kg/ha		
July 27	66 a	65 a	63 b	1043 b	1508 a	1415 a	1275 ab	1444 a	1323 a	1247 ab
August 8	65 a	61 c	62 bc	909 bc	1082 b	675 c	732 c	838 c	1004 bc	981 bc
LSD (5%)		1			293			308		
C.V. (%)		2			21			21		

Means followed by the same letter are not statistically different at 5% probability level.

RDW, TN 88-63 the smallest and SUVITA-2 was intermediate between them.

SY was significantly affected by cultivars/dates of planting and managements/dates of planting interactions (Table 4). Late planting significantly reduced SY of all cultivars, except SUVITA-2, and all soil managements, except in mulched plots. SUVITA-2 was the lowest yielder at the first date of planting, but yielded as much as TN 88-63 and KN-1 in the second dates of planting. KN-1 yielded either equally or significantly lower than TN 88-63, in the first and the second dates of planting respectively. SY did not differ significantly among soil managements at each date of planting.

Potculture experiment

HST impeded the growth of cowpea seedlings (Table 6). The reduced growth remained consistent up to maturity as reflected by: few BN, delayed FBD and FD, reduced number of flowers per plant, low SDW at maturity and low SY under HST compared to LST treatments (Tables 6, 7). HST also tended to increase RDW and to reduce nodulation and total water consumed per plant throughout the growth cycle (Tables 7, 8).

SUVITA-2 showed less sensitivity to HST compared to the other two cultivars. It was the earliest, highest yielding and least water consumer of the tested cultivars (Tables 6, 7). Except for SL and BL, TN 88-63 tended to be intermediate between SUVITA-2 and KN-1. TN 88-63 and KN-1 experienced severe flower bud abscission and flowered after the effective night temperature had been well stabilized at about 25°C, after June 25 (Fig. 4). They were, thus, highly sensitive to high air as well as soil temperatures.

Soil moisture stress (SMS) had no effect on FBD, FD, M and number of flowers per plants. A ten day SMS beginning 38 DAP tended to increase SL, increased BL significantly and reduced RDW in HST pots (Table 8). It also significantly reduced SDW of all cultivars and SY of SUVITA-2 compared to no SMS and SMS at 15 DAP. A ten day SMS beginning slightly after flowering further reduced SY of SUVITA-2 to almost zero, but had no effect on SDW compared to the no SMS treatment (Table 8). SY of SUVITA-2 under no and SMS's 15 DAP were similar, but both were significantly greater than those of TN 88-63 and KN-1 at all SMS's. SY of KN-1 and TN 88-63 were not affected by SMS treatments. At all SMS's, SY of KN-1 was not significantly different from zero; whereas that of TN 88-63 was similar to that of SUVITA-2 under SMS 38 DAP and SMS slightly after flowering (Table 8).

Discussion

Roots spend metabolic energy in uptaking nutrients (Vlamis, 1944). Under light, K^+ is uptaken in guard cells in which osmotic pressure increases and leaf stomata open (Penny & Bowling 1974). This enables transpiration and photosynthesis to take place (Salisbury & Ross, 1978). Roots also produce cytokinin and gibberelic acid (Salisbury & Ross 1978, Skene 1975). In the shoot, cytokinin promotes cell division, lateral bud development, organ formation, chloroplast development and delays senescence; whereas gibberelic acid, in combination with cytokinin, promotes cell expension. Increased respiration at the expenses of biosynthesis, that may occur under supraoptimal soil temperatures (40°C or greater), approaching the physiological

Table 5 Branch length and maturity dates as affected by soil managements; and stem length and shoot dry weight of cowpeas as affected by cultivars/soil managements at Loumbila/Ouagadougou, Burkina Faso, 1985.

Soil Management	Branch length (cm)	Maturity dates (DAP)	Stem length			Shoot dry weight		
			SUVITA-2	TN88-63	KN-1	SUVITA-2	TN88-63	KN-1
				cm			gr/plant	
– Flat beds	71 c	62 b	24 e	47 bcd	35 cde	39 e	61 de	87 abcd
– Flat beds converted to tied ridges 3 weeks planting	106 b	64 a	31 de	61 ab	57 abc	70 cd	59 de	109 a
– Tied ridge beds	142 a	64 a	71 a	54 abc	46 bcde	106 a	84 abcd	91 abc
– Mulched beds	138 a	64 a	56 abc	61 ab	76 a	101 ab	76 bcd	106 a
LSD (5%)	18	1		22			28	
CV (%)	28	2		37			34	

Means followed by the same letter are not statistically different at 5% probability level.

Table 6 Seedling dry weight, stem length, branch number, branch length, total flowers per plant and seed yield as affected by cultivars and soil temperatures in potculture at Kamboinse, Burkina Faso, 1985.

Cultivars	Seedling dry weight		Stem length		Branch number		Branch length		Flowers per pl.		Seed yield	
	Soil temp.		Soil temp.		Soil temp.		Soil temp.		Soil temp.		Soil temp.	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
	gr/pl		cm		n°		cm		n°		g/pl	
KN-1	0.37 c	1.32 b	72 b	64 b	2.7 c	5.1 b	34 cd	45 bc	7 c	19 bc	1 c	3 c
SUVITA-2	0.47 c	1.57 a	36 c	37 c	4.0 b	4.4 b	25 d	25 d	19 bc	63 a	13 b	26 a
TN 88-63	0.34 c	1.22 b	109 a	58 b	4.4 b	6.8 a	94 a	45 bc	10 c	36 b	6 c	18 b
LSD (5%)	0.13		14		1.1		12		18		5	
CV (%)	19		28		29		31		86		57	

Means followed by the same letter are not statistically different at 5% probability level.

Table 7 Effects of soil temperatures and cultivars on flower bud formation (FBD), flowering (FD) and maturity dates (M); shoot dry weight (SDW); root dry weight (RDW); nodule rate (NR); and total water consumed (H_2OT) by cowpeas in potculture at Kamboinse, Burkina Faso, 1985.

Cultivars	FBD (DAP)	FD (DAP)	M (DAP)	SDW (gr/pl)	RDW (gr/pl)	NR (1-5)	H_2OT (ℓ/pot)
Soil temperatures							
High	62 a	80 a	94 a	27 b	7.1 a	1.1 b	41 b
Low	43 b	65 b	90 b	39 a	5.9 b	1.4 a	63 a
LSD (5%)	5	4	3	3	1.1	0.2	4
CV (%)	20	12	4	23	36	35	17
Cultivars							
KN-1	58 a	79 a	96 a	38 a	8.0 a	1.3 a	54 ab
SUVITA-2	51 b	64 c	89 c	26 b	4.7 b	1.1 a	49 b
TN 88-63	49 b	73 b	92 b	36 a	6.8 a	1.3 a	55 a
LSD (5%)	6	5	2	4	1.3	NS	5
CV (%)	20	12	4	23	36	35	17

Means followed by the same letter are not statistically different at 5% probability level.

limits would reduce nutrient uptakes (including K^+) and the production of cytokinin and gibberelic acid and, hence, adversely effect transpiration, photosynthesis and the overall plant growth and development.

Therefore, the low water consumed in spite of great RDW (that would suggest increased exploration of soil to tape more water and nutrients), and the low SDW and SY in HST versus LST pots (Tables 6, 7, 8) implied that: supra-optimal soil temperatures adversely affected nutrient uptake and root biosynthesis, reducing transpiration, photosynthesis and plant growth and development. The consequences were: low seedling dry weight 15 DAP, delayed FBD and FD (as the result of flower bud abscission), few BN and flowers per plant, and increased SL and BL in HST Pots (Tables 6, 7, 8). Thus, apical dominance appeared to have been reinforced by HST and increased vegetative growth at the expense of the reproductive growth.

Since in the 1984 field experiment supra-optimal soil temperatures occured in oxen ploughed plots, the delayed FBD and FD, and the reduced BN, SDW and SY in those plots (Table 2) could also be related to these adverse effects of HST. This is supported by the low RDW that can be ascribed to the combination of HST and SMS, particularly in early reproductive growth stage, shown in potcultures (Table 8). However, since the drought condition prevailed throughout the crop season in the field experiment in 1984, HST and SMS, not only reduced BN, but also SL and BL, which, in contrast, were increased in potculture (compare Tables 6 and 8 with 2).

The low SY of TN 88-63 and KN-1 in spite of their great RDW, water consumption and SDW compared to SUVITA-2 in potculture (Tables 6. 7. 8), suggested that supra-optimal air (effective night and day temperatures greater than 26°C and 33°C, respectively) and soil temperatures increased respiration, depleted photosynthates and consequently reduced root biosynthesis of both cultivars. This probably had an adverse effect on their

Table 8 Stem length, branch length and root dry weight as affected by soil temperature/moisture stress interaction; and shoot dry weight and seed yield of cowpeas as affected by, respectively, moisture stress and moisture stress/cultivars interaction in potculture at Kamboinse, Burkina Faso, 1985.

Moisture Stresses	Stem length		Branch length		Root dry weight		Shoot dry weight	Seed yield		
	Soil temp.		Soil temp.		Soil temp.			KN-1	SUVITA-2	TN88-63
	High	Low	High	Low	High	Low				
	cm				gr/pl		gr/pl	gr/plant		
No stress	72 ab	48 d	48 b	39 b	7.3 abc	5.1 cd	34 ab	2 e	28 a	15 bc
Stress 15 DAP	74 ab	66 bc	48 b	42 b	8.6 a	6.6 abcd	39 a	2 e	28 a.	11 bc
Stress 38 DAP	85 a	46 d	66 a	36 b	4.8 d	6.5 abcd	28 c	1 e	17 b	10 bcd
Stress slightly after flowering	59 bcd	52 cd	43 b	36 b	7.6 ab	5.4 bcd	32 bc	3 de	8 cde	13 bc
LSD (5%)	16		13		22		5	7		
CV (%)	28		31		36		23	57		

Means followed by the same letter are not statistically different at 5% probability level.

reproductive growth and resulted in delayed flowering and few flowers per plant and low SY (Tables 6, 7, 8).

In the subhumid climate, of Nigeria, soil temperatures above 36°C were reported to adversely affect plant vigor, nutrient (N, P and K) uptakes and SY of maize and soybean (Lal 1975). In the same climate, straw mulch and aluminum foil, which kept soil temperatures at 5 cm depth at 15:00 hrs below 34°C, significantly increased SY of cowpeas as compared to other soil treatments (viz. black plastic, clear plastic, ridges and bare flat) which increased soil temperatures above 40°C during the first crop season. During the second season, none of the treatments had a significant effect in cowpea SY, since soil temperatures did not rise above 30°C. These reports agree with the findings of the present study. HST within the range of 45–50°C have also been reported to have an adverse effect on other crop species (Franco 1961, Münch 1913 and 1914).

Supra-optimal air temperatures were reported to delay or inhibit FBD (Patel and El Madina, cited by Hall and Patel, 1985) and to cause increased floral abscission, male sterility and embryo abortion, with decreased number of pods/m^2 and SY (Warrag and Hall 1983, 1984). In the present study, FBD was delayed by supra-optimal air as well as soil temperatures in the field experiment in 1984 and in potculture in 1985 (compare Tables 2, 3 and 7). Furthermore, flower bud abscission occured for all cultivars (with SUVITA-2 being less sensitive as compared to KN-1 and TN 88-63) due to both supra-optimal air and soil temperatures. Thus, they delayed FD, reduced the reproductive growth duration and, adversely affected SY.

SUVITA-2, by flowering early and giving a high SY compared to KN-1, under high air and soil temperatures appeared to be more resistant to those climatic factors than the latter. TN 88-63 was intermediate between them.

The drastic SY decrease of SUVITA-2 when subjected to SMS's during the RGS's in potculture confirm reported results (Turk et al 1980, Ziska and Hall 1983). Whereas the lack of significant effect of SMS on SY on TN 88-63 and KN-1, in potculture, suggested that lack of resistance on HST prevented them from responding to SMS treatments. The predominance of the detrimental effect of HST over that of moderate SMS appeared to be well illustrated in the 1985 field experiment; only the HST-resistant cultivar, SUVITA-2, and the mulched plots, for which soil temperature did not heat up to 40°C, did not have their M and SY adversely affected by HST and SMS's at the end of the crop season.

Resistance to HST and use of production practices that reduce soil temperatures, (such as straw mulch) thus appeared to be prerequisites in preventing severe SY losses under high heat and drought conditions of semi-arid West Africa.

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26 Grain Legume Production Strategies in the Semi-Arid and Arid Areas of Kenya

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Abstract Over 80% of land in Kenya lies in the semi-arid and arid zones characterized by low (400-800 mm) and erratic rainfall. The population pressure in the high potential areas has resulted in the migration of people into these areas. Crop failures in these areas are primarily due to inappropriate production techniques and frequent occurrence of drought.

The paper discusses rainfall and moisture availability in relation to the growing duration of the commonly grown dryland grain legumes such as pigeon pea, cowpeas, green grams, beans and other minor pulses in farming systems based on various cereals like maize, sorghum and millets.

Implications of breeding for drought tolerance and utilization of available genetic variability to counteract prevalent moisture stress conditions in the semi-arid areas are discussed.

Introduction

There is a high demand for arable land in Kenya today than ever before due to high population pressure. Using a combination of climatic indicators, such as rainfall, its distribution, temperature and evapotranspiration it has been estimated that 10% of Kenya's land is semi-arid, 49% arid and 23% very arid. With the resources presently available, only semi-arid and arid lands are considered marginally suitable for crop production. Most of the semi-arid and arid lands are found in Eastern, Coast and Rift Valley Provinces while the very arid ones are located in North Eastern Province. Crops grown in these areas include cereals (maize, sorghum, millets), grain legumes and root crops.

Most of the grain legumes are known to thrive under unfavourable stress environments. In Kenya they are widely grown in semi-arid and arid areas where rainfall is bimodal and averages 400-800 mm annually.

The major grain legumes grown in these areas are beans (*Phaseolus vulgaris*) pigeon pea, (*Cajanus cajan*), Cowpeas (*Vigna unguiculata*), grams (*Vigna radiata*) and dolichos bean (*Dolichos lablab*). The legumes are grown in mixtures with cereal crops such as maize, sorghums, and millets on an area of 594,000 ha. (FAO production year book 1984). Although the hectarage on which these crops are grown is high, the production level is low due to low grain yields per hectare.

Farmers in these areas grow local landraces which cannot utilize the limited moisture efficiently, therefore there is need to develop improved varieties and production technologies to alleviate the yield levels in dry areas. This paper discusses the agroclimatic conditions prevalent in these areas, their effect on crop production and implications on varietal improvement.

Agroclimatic Environments

Kenya is divided into six agro-ecological zones defined on the basis of temperatures and rainfall characteristics (precipitation and evaporation). The main zones are based on the availability of water, while the zone groups are formed by temperature belts (Jaetzold and Schmidt 1983).

The first maize zones (I and II) constitute the humid and sub-humid areas; zones III and IV are the semi-humid and transitional areas, while zones V and VI are characterized by semi-arid and arid conditions (Table 1). Each of the zones is further classified into lowland (0-900 m) medium (900 1850 m) and highland (> 1850 m). (Braun *et al* 1982).

Table 1 Agroclimatic zone classification based on rainfall temperature and altitude (Braun 1982)

Zone	Classification	Average annual rainfall (mm)	Mean annual temperature °C	Altitude (m)
I	Humid	1100-2700	10–16	2450-3050
II	Sub-humid	1000-1600	12-18	1850-2450
III	Semi-humid	800-1400	16-18	1850-2150
IV	Semi-humid to semi-arid	600-1100	16-20	1500-2150
V	Semi-arid	450-900	20-24	900-1500
VI	Arid	300-550	24-30	0-900

Rainfall, Temperature and Evapotranspiration

The major climatic factors influencing grain legume production in semi-arid and arid areas of Kenya are rainfall, its distribution and reliability, temperatures and evapotranspiration.

The farmer in the semi-arid areas of Kenya must cope with the vagaries of rainy season that is short and highly unpredictable; intense rainfall interspersed with sudden drought; soils with low infiltration capacity and thus greater water erosion hazard; and finally high evapotranspiration rate during the growing season.

In most parts of Eastern Kenya, rainfall is bimodal with distinct peaks in April and November. This seasonal pattern of rainfall is dominated by the movement of the Intertropical Convergence Zone (ITCZ) which is slow and broad in April (Long rains) and quicker in October-November (Short rains) (Nieuwolt 1977).

The bimodal rainfall pattern common in Eastern Kenya is replaced by monomodal pattern found in the semi-arid areas west of Rift Valley (Perkerra) with peak in June-July. However, at the coast, the larger part of rain falls in the months of March-June with relatively low rainfall during October-December.

Brief description of the six testing sites used in the experiments reported in this paper are given in Figures 1 and 2 and discussed as follows:

Rainfall

Rainfall amounts received in different agro-ecological selected sites varies between years and seasons (Figure 2). At *Katumani* (1570 m); agro-ecological zone UN4, the mean annual rainfall is 659 mm spread over 64 days with year to year variation from 400-950 mm. *Kampi ya Mawe* (1120 m), agro-ecological zone LM4, received 670 mm annually in 59 days. The amount of rainfall received during long and short rains is roughly similar for both the stations (Figure 1).

Makindu (900 m) which lies in agro-ecological zone LM5 receives the least amount of rainfall (544 mm) annually distributed over 40 days. Short rains (280 mm in 19 days) are more reliable than long rains (183.8 mm in 13 days) Table 2.

Marimanti (160 m L5) receives the highest annual rainfall of 935.9 mm spread over 50 days with both seasons receiving about 400 mm in 21 days each.

Perkerra (1066 m, LM5) received 665 m rainfall annually spread over 81 days with a monomodal peak in June-July.

Although *Nanyuki* (1948 m, UH4) has bimodal rainfall with peaks in April and November, it receives substantial amounts during the supposedly

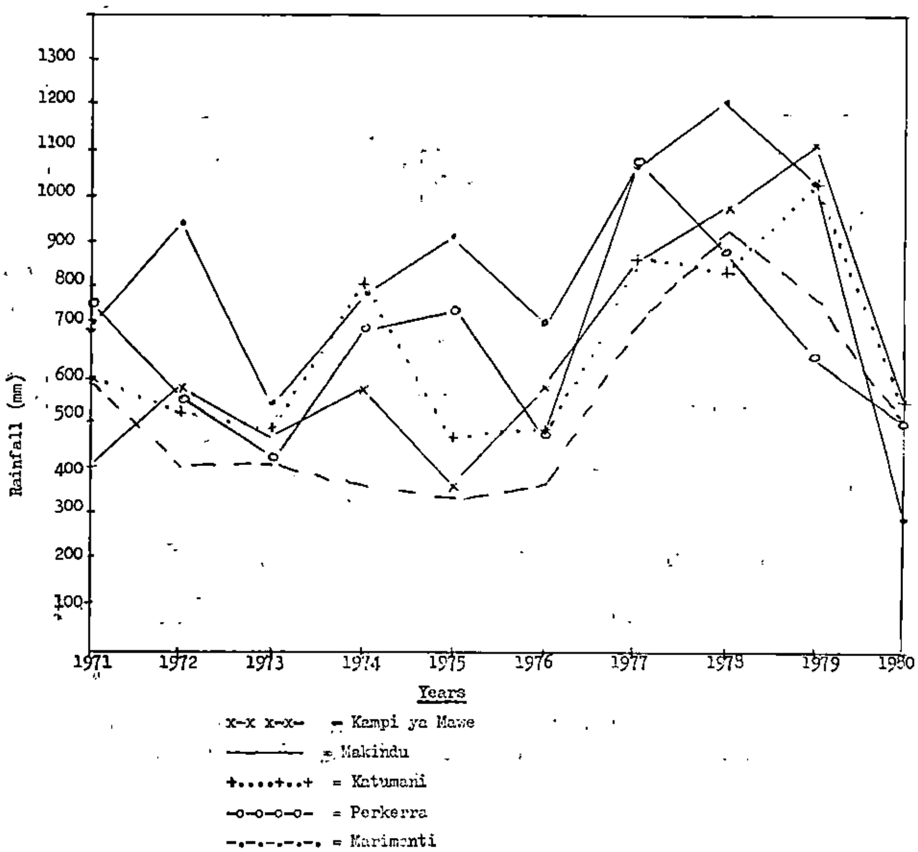

Figure 1 Variability of annual rainfall in semi-arid and arid areas of Kenya

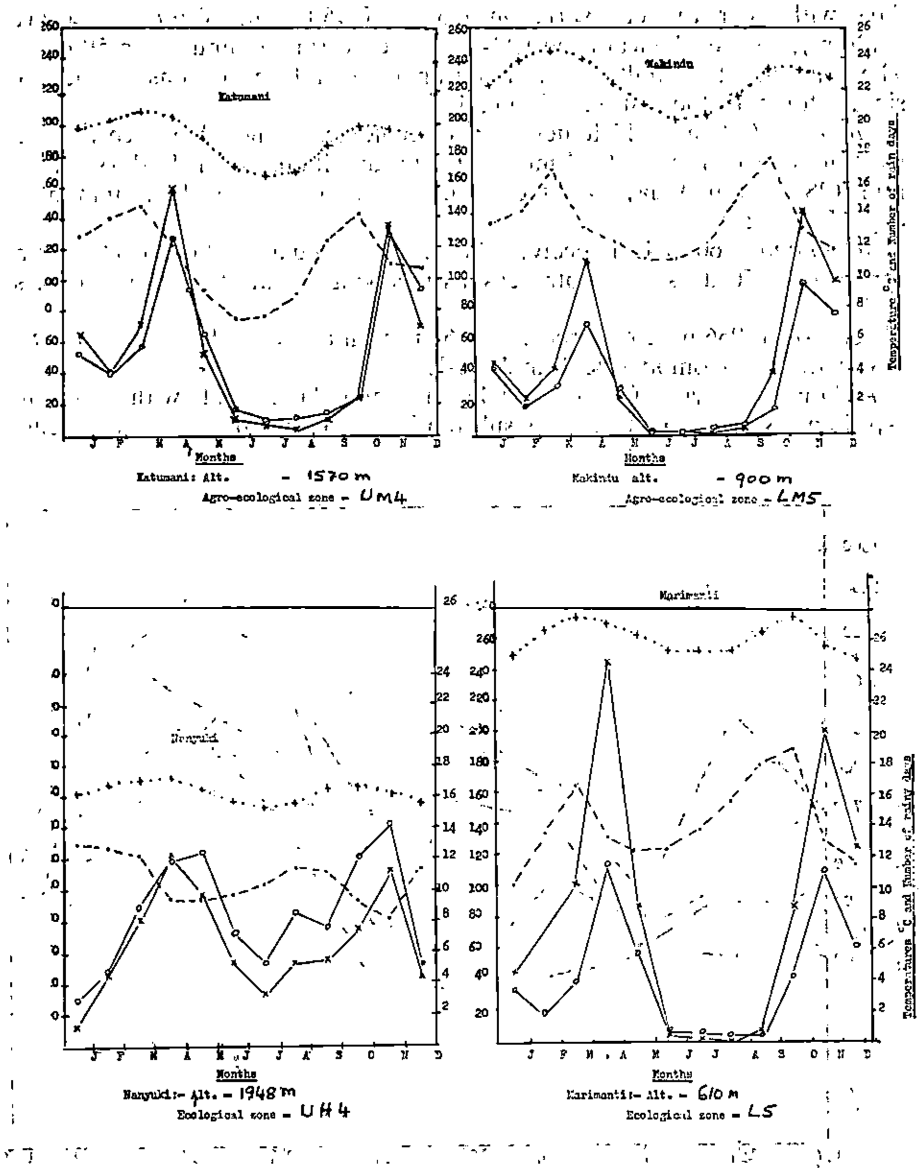

Figure 2 Mean rainfall, number of raindays, temperatures and evapotranspiration for six different agro-ecological zones in semi-arid and arid areas of Kenya

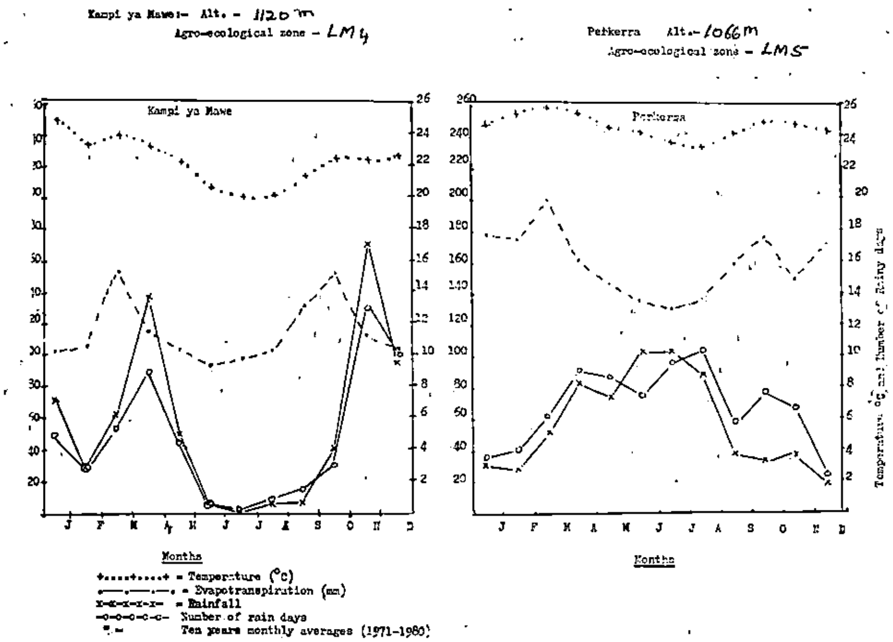

Figure 2 (continued)

Table 2 Seasonal distribution of rainfall and rain days* for different locations of semi-arid and arid areas in Kenya

Station	Altitude (m)	Long rains March-May		Short rains October-December		Annual (Mean of Ten Years seasons)	
		Rainfall (mm) days	Rain days	Rainfall (mm) days	Rain days	Rainfall (mm) days	Rain days
Katumani	1600	284.0	24.9	233.4	25.2	659.2	64.5
Kampi ya Mawe	1120	234.1	18.7	309.5	26.6	670.0	59.5
Makindu	997	183.9	13.6	280.0	19.2	544.0	40.8
Marimanti	610	437.3	21.3	420.8	21.8	935.9	50.2
Perkerra	1066	409.9	37.9	91.6	16.6	665.1	81
Nanyuki	1948	304.6	28.7	229.6	31.6	778.6	102.6

* Mean of 10 years 1971-1980.

dry months of June-September unlike Katumani, Makindu, Kampi ya Mawe and Marimanti stations.

Temperatures

Marimanti and Perkerra have the highest mean temperatures ranging from 23°C-28°C. Makindu and Kampu ya Mawe have similar mean temperatures ranging from 20°C-25°C.

Nanyuki has the lowest mean temperatures with a narrow range of 16-17°C while Katumani has a wider range of 16-21°C.

The lowest mean temperatures for all the stations is experienced during the month of June, July and August.

Evapotranspiraton

Crop water loss through evaporation is generally high before the onset of the rains in the two seasons (Figure 2). In most of the sites, evapotranspiration rates are higher than rainfall throughout the year except in a few days during the peak months of April and November. However, in Perkerra where mean temperatures are amongst the highest, evapotranspiration rates are higher than rainfall throughout the year. On the other hand, Nanyuki with the lowest mean temperatures has also the lowest mean evapotranspiration rates.

Soils

The availability of adequate soil moisture for crop growth depends not only on the amount and distribution of rainfall but also on the water holding capacity and soil types and depths super imposed by evaporation rates. The major soils found in the semi-arid and arid areas of Kenya are alfisols which have poor structural stability with a tendency to surface sealing, low infiltration and therefore high erosion susceptibility. The subsoils have low porosity and poor water storage capacity hence residual moisture limited. Type and time of tillage also influence the soil moisture status.

Grain Legume Production and Utilization

Grain legume production in Kenya is characterised by a high degree of diversity indicated by the number of crops and their distribution into varied agroclimatic conditions. The legumes are grown annually on an area 1,187,000 ha comprising beans 64%, cowpeas 22%, pigeon pea 10% and green grams, dolichos lablab and chickpea etc 4%. (Table 3). Bean and cowpeas are invariably grown in all the provinces except North Eastern while pigeon peas is predominantly grown in the Eastern, Coast and Central Provinces.

Eastern Kenya which is largely semi-arid and arid contributes 58% of the total hectarage under various grain legumes. The relatively more drought tolerant grain legumes like cowpeas, pigeon peas, green grams and lablab bean occupy 56% of the total area.

Although livestock is an integral part of the farming system in the semi-arid and arid areas, farmers generally keep the animals mainly to generate cash. (Rukandema *et al* 1983, Tessema *et al* 1985). Meat consumption in

Table 3 Estimated areas under grain legumes in 1974-75 crop season in Kenya (000 ha)

Province	Bean		Cowpea		Pigeon pea		*Others	
	Pure	Mixed	Pure	Mixed	Pure	Mixed	Pure	Mixed
Eastern	25.3	259.3	10.1	198.3	0.0	104.5	0.2	30.0
Central	8.4	224.0	0.0	7.8	0.0	4.2	0.0	0.0
Nyanza	3.5	70.1	0.0	2.9	0.0	0.0	0.0	1.7
Western	11.5	136.9	0.4	12.8	0.0	0.6	0.8	
Rift Valley	0.9	6.1	0.0	0.0	0.0	0.0	0.0	0.0
Coast	0.3	17.2	1.2	37.7	0.0	6.5	0.1	4.0
Total	763.5		271.2		115.2		37.4	
Average yields kg/ha	500		400-500		300-400		400	

* Others include green grams, colichos lablab.
Source Kenya statistical abstract 1978.

these ares is generally low and the protein requirements are mainly met through grain legumes.

Dried grains are boiled in different preparations in combination with cereals or as split grains. The unripe green seeds of pigeon pea, cowpea and beans are used in various preparations. Cowpea leaves are an important source of leafy vegetables. Dolichos lablab and pigeon pea are served on ceremonial occasion by certain ethnic groups.

The leaves and stalk of pigeon pea, cowpea, lablab bean and green grams after harvest are used as livestock feed in the semi-arid and arid areas to supplement protein requirements.

Grain legumes improve the soil fertility through fixation of atmospheric nitrogen and leaf fall. The subsistence farmers in the semi-arid areas can hardly afford to buy expensive inputs (fertilizer etc) and incorporation of grain legumes into their farming system improves the fertility levels of companion or succeeding crops.

Varietal Improvement

A grain legume improvement programme at National Dryland Farming Research Station, Katumani was initiated in 1980 with the objectives of developing early maturing drought resistant, high yielding, good quality, insect and disease resistant/tolerant, cultivars with wide adaptation (Shakoor, *et al* 1984, Omanga *et al* 1986).

Moisture availability is the major limiting factor in the marginal areas. The number of rainy days for each growing season varies from 13 to 25, spreading over approximately 70 days. The rainy days are confined to the early crop growth stages subjecting the reproductive and grain filling phases to drought.

The most promising ideotype of these grain legumes should possess an extensive deep root system, high harvest index, early maturity and drought tolerant physiological and morphological traits (Shakoor 1983, Sojka 1984, Rachie *et al* 1978). Tremendous genetic variability for most of these traits exists in the local landraces (Shakoor *et al* 1984a.b.c.).

Improved varieties of cowpeas both early (80-90 days) and extra-early (60-80 days) have been developed. Their yield potential varies from 1200 to 1600 kg/ha (Table 4). Three distinct maturity groups in pigeon pea (early < 150 days; medium 150-180 days; late 180-300 days) have been identified to fit in various agro-ecozones of semi-arid areas. The varieties 60/8; 50/3 belong to the early maturity group; 576/3; 81/3/3 and 657/1 medium group and 2, E31/4 late group with yields of 1500, 2000 and 2300 kg/ha respectively. In green grams, No. 26 and No. 22 mature between 65-90 days while No. 7 takes 91-115 days with yield ranging from 1000-1600 kg/ha. for Dolichos bean the maturity period of improved varieties varies from 100-120 days and yield ranges from 2000-3000 kg/ha. Katumani B1, B2 and B9 are the improved varieties of beans with determinate growth habit developed at National Dryland Farming Research Station, Katumani. Improved *Mwezi moja* strains MM40, MM18 are the earliest maturing beans with desirable cooking quality. Chickpea is generally grown on residual moisture in patches of black cotton soils as a cash crop. The variety IC 83110 matures in 85-100 days and yields 150 kg/ha.

Table 4 Varietal Adaptation of Grain Legumes and their Agro-ecological Requirements

Crop	Variety	Days to 75% maturity	Altitude (m)	Amount of rainfall (mm)	Expected yields (kg/ha)
Cowpea	KVU419	75-80	0-1300	190-250	1400
	KVU353	65-75	0-1600	"	1200
	IT82-22	60-75	0-1500	200-400	1600
	IT82-18	81-90	"	"	"
	Machakos 66	85-90	0-1500	200-400	1600
Pigeon pea	60/8	130-150	0-1600	250-600	1500*
	50/3	140-150	0-1600	"	1500*
	576/3	150-170	0-1600	300-650	2000
	81/3/9	"	"	"	"
	657/1	"	"	"	"
	2	230-300	500-1800	500-800	2300
	E31/4	"	"	"	"
Green grams	No. 26	65-70	0-1600	190-250	1000-1600
	No. 22	70-90	0-1600	200-300	700-1300
	7	9-115	0-1600	200-300	900-1400
Dolichos bean	DL1002	100-110	0-2200	200-800	2000-3000
	DL1009	110-120	0-2200	200-800	2000-3000
	DL1106	105-115	0-220	200-800	2000-3000
Beans	Mwezi Moja	60-70	700-1500	200-400	1500
	Kat.B1 & B9	65-70	700-1500	200-400	1500-2000
Chickpea	IC83110	85-100	0-1500	200-400	1500

* Yield for one first season.

Improved Production Strategies

In order to achieve high yielding potential of the improved varieties, appropriate agronomic production techniques need to be worked out for each agro-ecological zone. In semi-arid areas with bimodal rainfall pattern receiving similar amount of rainfall in each season e.g. (Katumani, Kampi ya Mawe and Marimanti) early maturing grain legume cultivars (60-115 days) can be successfully grown. In situations such as Makindu where one season is more reliable (short rains); most of the early maturing legumes can be grown except in less reliable season (Long rains) where extra early cowpeas (KVU 419, KVU 48) and green grams (No. 26) may be grown.

Traditionally, pigeon pea is normally planted during short rains (Oct.-Nov.). The late maturing pigeon pea cultivars use both seasons to reach the reproductive stage and can be grown in the various agro-ecological zones with bimodal rainfall except in situations where the second season rain is inadequate. In such cases, medium maturing varieties are recommended.

The medium maturing pigeon pea varieties can be grown in bimodal rainfall pattern as from the month of October and will flower after the onset of long rains (March-April). These cultivars are therefore able to utilize the second season moisture more efficiently than the late maturing ones for grain production. Early maturing varieties of pigeon pea are equally suitable for both monomodal and bimodal rainfall patterns. In bimodal rainfall areas, the crop planted during October/November (Short rains) is harvested before the start of long rains, and if the crop is ratooned, the second harvest will be realized in July/August. In agro-ecological zone UH4, where temperatures are relatively low the medium maturing varieties of pigeon pea can perform better. Like the Perkerra, ecozone LM5 where rainfall is monomodal, early and medium maturing cultivars can be planted at the beginning of the season, and followed by extra-early fast growing legumes such as cowpea and green grams as relay crops.

The traditional cropping systems in the semi-arid areas is mixed cropping. All these grain legumes have been grown in combination with one crop or the other, or with a cereal crop. The rate of crop failure is more frequent in lower altitude agro-ecological zone 5. In these areas therefore, a combination of extra-early cereals (Proso millet, bulrush millet etc.) and extra-early cultivars of cowpea and green grams will be most ideal.

Future Prospects

I. Reduction in maturity, without appreciable loss in grain yield of these grain legumes will continue as one of the major objectives in breeding programmes.

II. Introduction of new grain legume drought resistant species such as black gram (*Vigna mungo*), tepary bean, and Marama bean etc. will be exploited.

III. Breeding for insect and disease resistance/tolerance will go hand in hand with development of new drought resistant high yielding varieties.

IV. Appropriate agronomic packages for the exploitation of high yield potential of new varieties will be developed for the different agro-ecological zones.

Conclusions

Grain legume production in semi-arid and arid areas of Kenya can be stabilized through the introduction of appropriate early maturing varieties suited to each agro-ecological zone. Some of the improved pre-released grain legume varieties developed at N.D.F.R.S. Katumani have shown an impact at farmers level, while in other cases the material is in advanced stages. It is hoped that in the near future, improved varieties combined with appropriate production technology will go a long way in enhancing the deteriorating food situation in the semi-arid and arid areas of Kenya.

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27 Storage of Food Grains in the Savanna Zones of Northern Nigeria

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Introduction

The improvement of the yield of food grains together with their conservation is one sure solution to the problem of hunger prevalent in the semi-arid regions of sub-saharan Africa. Efforts at improving agricultural production have always been concentrated on increasing production *per se* through the breeding of high-yielding varieties with little emphasis on the conservation of what is produced. Since all that is produced cannot be consumed immediately, there is always a need for adequate and efficient storage facilities to save the excess crop that is produced from deterioration and waste.

The objectives of storage are to ensure steady availability of produce and stable market food prices and thereby reduce the seasonal fluctuations of these prices; to enable farmers and producers sell their produce at times when they can get the best prices; to eliminate losses in quantity and quality and to ensure that healthy seeds are available for planting in the next cropping season.

The main food grains produced in Nigeria are sorghum, millet, maize, cowpea, rice and wheat. The bulk of these grains is produced in the northern parts of Nigeria, which occupies approximately between latitudes 7°N and 14°N and are grown as sole crops or as mixtures. The different varieties grown and choice of variety are influenced by the type of savanna, as well as varietal preference of farmers.

Investigations into the problems of food grain storage in the northern states of Nigeria have been primarily carried out by the Institute for Agricultural Research, Samaru. These investigations have concentrated on identification of the main pests of the major grains, assessment of the damage caused by them and the development of methods of controlling them.

This paper reviews the information available on a) the problems associated with the harvesting and storage of food grains in the Nigerian savannas; b) the traditional methods of grain storage and associated problems in the area; c) factors influencing food grain losses; d) the scientific investigations and recommendations to combat these problems and future research needs in post harvest loss reduction and prevention.

Food Grains of Northern Nigeria – Production, Preharvest and Harvest Losses

Sorghum and Millet

Sorghum, commonly called Guinea corn, and millet constitute the major cereal crops grown in northern Nigeria. Almost all the 4.2 million tons of sorghum and 3.1 million tons of millet produced in Nigeria (Anon 1979a & b), are grown in the northern states. These two crops form the main staple food of the people of the north and, therefore, the production and storage of these two crops have an established history in this region (Giles 1964b).

The climate of northern Nigeria permits only a single crop of sorghum and millet to be grown each year. Sorghum is harvested between November and December while millet is harvested about August. Both crops are harvested manually but, unlike millet, sorghum can be harvested in two ways. Either the stalks are cut at the base, arranged in windrows and left to dry in the field and the heads are cut later, bundled and taken into storage, or the heads are severed off the stalk without cutting down the stem, left to dry and later bundled for storage in granaries without threshing. The latter method is also used for millet.

Preharvest, harvest and postharvest losses

Losses occur before harvest and during the various harvesting and post harvesting operations. Field loss assessment in sorghum at various locations in the savanna zones of Nigeria was carried out by Kalkat and Ohiagu (1982). It was found that sorghum attains physiological maturity at about 30% grain moisture content and that harvesting must therefore be made at grain moisture levels of between 14% to 30%. Preharvest and harvest losses were comparatively low when sorghum was harvested early. Losses ranged from 5.5% to 6.7% at 27.3% to 26.5% grain moisture levels respectively but increased to 39.5%–82.8% at grain moisture contents of 5.5% (Kalkat and Ohiagu, 1982).

A major source of grain damage and grain loss in northern Nigeria occurs during threshing. Traditional threshing and shelling methods are laborious and time-consuming. Usually, threshing involves piling the heads in heaps and beating with sticks or placing the heads in a sack or mortar and pounding with a pestle. Each method results in grain loss and grain damage. Kalkat *et al* (1982) estimated that the threshing loss of sorghum, which included grain left on threshed heads, grain blown with the chaff, grain scattered during beating and grain buried in loose soil at the threshing site, varied between 1.3% and 8.5%. Grain moisture content at which threshing loss could be minimized was between 4.9% and 9%. Further grain loss occurred during bundling and on farm haulage to threshing sites and stores.

Maize

Most of Nigeria's maize is normally grown in the forest zone, but, within the last few years, the maize crop has become more and more important in the savanna zones, mainly due to the performance of this crop in some of the Agricultural Development Projects. Maize production has been accepted in the savanna ecological zone so rapidly that millet is loosing ground to it (Anon, 1984). There is a single crop of maize in northern Nigeria although, in some parts of the southern Guinea savanna, maize can be grown twice a year. The actual hectarage grown to maize in the savanna is uncertain, but it is estimated that of the 1.9 million hectares grown to maize in Nigeria, 15% is now grown in the savanna zone (Anon, 1984). In the southern Guinea savanna zone where maize could be grown twice a year, early maize is harvested between June and August and the late maize from September to December when the single crop is also harvested. At harvest, the crops are removed from the standing stalk and brought to the granary where they may be dehusked and stored on the cob or shelled before storage. The early harvested maize in the storage Guinea savanna contains more moisture than the single crop harvested later in the dry season and will therefore be susceptible to damage and deterioration if not properly dried.

Cowpea

Cowpea is an extremely valuable crop both as a source of revenue and as an important item in the diet of Nigerians. Its production in Nigeria is estimated at 800,000 tons annually with over 80% of this grown in the savanna zones of northern Nigeria (Raheja, *et al* 1979). Here, the crop is grown as a component of a mixed cropping system with very little grown as a sole crop because of production problems, the most important of which are insect pests. Cowpea is mostly stored unthreshed by peasant farmers in mud granaries; with the pods providing a good deal of protection to the seeds within. In urban centres, however, cowpea is stored in sacks in stores before being sold to consumers. Considerably high standard of storage hygiene is called for in order to reduce losses which occur in farmer's stores, government stores and warehouses.

Traditional Storage Structures and Methods of Food Grain Storage in Northern Nigeria

Traditional methods of grain storage have been in use for a long time by the Nigerian peasant farmer. The various methods employed succeed to varying degrees in protecting the stored produce against insect damage. The various structures and methods of storage are as follows:

"Rumbu" Storage

The bulk of the food grains grown in northern Nigeria is stored in earthen granaries or granaries made of plant material commonly known as the "rumbuna" (Hausa) (Singular "rumbu"). Apart from areas in the dry northeast, where building clay is difficult to obtain, the grainary reflects permanence and is used in settled areas. It is fire-resistant, termite, thief and rodent proof. It is highly suitable for threshed grain. The grass mat bin, on the other hand, allows free flow of air and farmers use this very often to store millet harvested during the rainy season. Both types are built into a cylindrical structure with a dome-shaped top 'capped' with thatch (Agboola, 1985). Some of these structures are raised from ground level with supports made of mud or wood. There is an access window near the top through which grains are loaded. Grains can be stored threshed or on the head. The various types of "rumbuna" have been described by Giles (1964a).

The weather in northern Nigeria during the harmattan months does not favour the development of insect pest populations. Only a few major pests such as *Sitotroga cerealella* persist during this period. Storage in earthen granaries appears to shield these insect pests from the weather. The "rumbu" is limited in its efficiency because the walls are porous to air so after the initial infestation by the insect pests, there is continuous supply of oxygen to sustain the insect population within the rhumbu.

In-hut Storage

Food grains meant for the farmer's consumption and for seed are sometimes stored in the farmer's house in simple containers like earthern pots, calabash and tins. No measures are normally taken to control insect pests. Where attempts are made, the containers are sealed to provide airtight conditions which kill some of the insects. In some cases, harvested crops are heaped on the floor in one corner of the living room without additional care. The crops may also be placed on raised platforms above fireplaces to aid drying and repulsion of insects. Maize cobs, sorghum or paddy rice heads may be tied to rafters of house roofs with fire made inside the house to dry the grains. In-hut storage of grains is not very effective since such grains are highly susceptible to rodent damage and infestation by insects. In addition, grains exposed to smoke from fires becomes smoke tainted and looses quality.

Underground Pit Storage

The pit stores are found mainly in the dry savanna areas of Borno state and are of various designs and sizes and used mainly for storing grains. They are generally deep trenches lined with straw and sealed with mud. In some areas, the sides of the pit are plastered with cement. There are various reports on the mode of sealing of these pits. Pit storage is claimed to reduce attack by insects, theft of stored produce and reduces the fire hazard. It has serious limitations, however, because grains stored in pits are prone to rodent attack, there is an increase in the humidity and moisture content of the grain and accumulation of carbon dioxide.

Storage on Platforms

Unshelled maize, panicles of paddy rice, unthreshed sorghum, millet and cowpeas are placed on platforms made of grass. The platforms are supported by wood or bamboo poles. In the southern parts of the country, the platforms have a well knit thatched roof supporting structure to cover the cobs. These are popularly known as *cribs*. Some farmers make a fire underneath the cribs to dry the grains and to destroy insects. Fire accidents have occasionally resulted from this practise, leading to the total destruction of the produce.

Farmers in northern Nigeria have traditionally used materials such as ash, pepper, vegetable oil and palm oil to protect their stored grains. Some of these materials have been found to be effective and a critical appraisal of the various methods of application and use are currently being investigated. Palm oil has been used by peasant farmers in protecting cowpea in the store. It is believed that palm oil is effective because the vapour given out interferes with the insects breathing and suffocating them. Investigations carried out at the International Institute for Tropical Agriculture, (IITA) in 1975 showed that *Callosobruchus maculatus* on cowpea can be controlled for at least 6 months using groundnut oil at the rate of 5-10 ml per kilogramme of seed.

Major Factors Affecting Food Grain Losses in Northern Nigeria

It is estimated that of the 10 million tons of food grains produced annually in Nigeria (FAO, 1975), between 1.5-2 million tons is lost due to poor storage. In monetary terms, this amounts to between 300-400 million Naira (Agboola, 1985). Loss in quality and quantity of the major food grains in northern Nigeria is caused principally by insects, microorganisms, rodents and, occasionally birds. Of all these factors, the most studied and the most important are insects. It is estimated that 100 insect pest species are associated with stored crops. In Nigeria, 20 species are very common and important (Cornes, 1973). These are mainly beetles and moths. Some of these insects begin their attack in the field and continue in the stores.

Considerable information is available on the infestation and damage to stored sorghum in northern Nigeria. The main causes of damage to sorghum grain in storage are insects and rodents. Giles (1964b) reported that at least 4% of all the sorghum and millet grown in northern Nigeria is lost annually due to stored product insects. In sorghum alone in 1962, this was equivalent to a weight loss of 115,000 tonnes which is sufficient to meet the cereal needs of some 1.3 million people, (Ayertey *et al* 1982). Caswell, (1978) reported that about 1.4% of sorghum produced in northern Nigeria was lost annually to insect pests, the most important being *Sitophilus oryzae* (L). *Sitotroga cerealella* (Oliv.) and *Rhizorpertha dominica* (F).

Millet is harvested at about the peak of the rainy season and the major problem is therefore deterioration due to mould infection. Moulds can cause the discolouration of produce and also affect the flavour and odour of the meal 'Tuwo' locally prepared from millet. Limited work on the entomological problems of millet storage has been done. Damage by birds is most important in millet. Amatobi, (1980) attributed losses of up to 70% in early millet and 20% in late millet, in Kano state to bird damage. Damage by rodents occurs virtually throughout the year, although reliable estimates of losses are few.

Maize is attacked prior to harvest and in storage by *Sitophilus zeamais* (Motsch), resulting in up to 14% damage and 20% loss in weight (Ayertey, 1980). Insect pest damage to maize has been estimated at 7% during the dry season, increasing to 12% during the wet season. As a result of the increasing importance of maize in northern Nigeria, problems associated with the storage of the crop are now being investigated.

Cowpea suffers the highest amount of damage in storage due to insect pests. Infestation by the main insect pest of stored cowpea – *Callosobruchus maculatus* starts from the field and builds up in the store where it is estimated to cause 90% of the damage to cowpea. Caswell (1980) estimated that 10% of the grains is damaged by January and this rises to about 50% July, resulting in an annual loss of 4%.

Loss Reduction Strategies Developed at the IAR

Insect control measures have received some research attention at the Institute for Agricultural Research. Infestation and damage done by insects to various grains in northern Nigeria and methods of reducing these have been investigated and recommendations arising from these investigations are passd on through the Agricultural Extension and Research Liaison Services (AERLS) at Samaru to the Ministries of Agriculture in the various states.

Chemical Methods

Giles (1965) recommended the treatment of sorghum stored on the head in mud granaries with 0.5% Lindane dust at the rate of 10 ppm. This treatment was found to give protection of the grain for 18 months (Caswell, 1980). A further refinement of this method was the application of 1½ match boxes full of lindane dust as sandwich between layers of 25 kg of heads or grain stored in mud granaries. However, because of the deleterious effects of

Lindane and the recent reports (Anon. 1976) of Lindane resistance in several storage insects, including those found on sorghum, alternative chemicals which are less toxic are being examined. Pirimiphos methyl (Actellic) applied as 2% dust at the rate of 10 ppm and 15 ppm was found to be effective and safer than Lindane. While Lindane has an LD_{50} of about 100 mg/kg, Primiphos methyl has an LD_{50} of over 1000 kg/kg. Several insecticides used on other grains have been ineffective against cowpea pests. However, the value of *phostoxin* as a fumigant for cowpea has been demonstrated at the IAR. Fumigation with phostoxin at the rate of 1 tablet per 100 kg of seed has been effective. To prevent reinfestation, application of Pirimiphos methyl (Actellic) at 10 ppm to the surface of bags either before or after fumigation has been recommended. No harmful residues have been detected and the treatment does not affect germination.

No-chemical Methods

The use of non-chemical methods of pest control in storage has also been investigated. For small scale storage, grains can be stored in small containers such as metal drums, plastic cans, kerosine tins and thick gauge polythene bags which can be made airtight. The polythene bags can be inserted inside hessian sacks to add strength. Dry maize, rice, sorghum, millet or cowpea grains can be stored in all these containers. This is hermetic storage which is based on the fact that when insect-infested grains are placed in airtight sealed containers, the insects eventually use up the available oxygen and become asphyxiated (O'Dowd 1971). The efficacy of this method can be enhanced by treating the grains with a suitable fumigant (Phostoxin) before it is sealed up. The fumigant kills off all the insects and the stored grains can remain undamaged for several years. Grains stored under hermetic conditions remain dry and clean and do not lose their germinability and palatability. One method developed at the IAR (O'Dowd, 1971) for storing cowpeas is particularly effective. This involves the use of two bags, one made of baft and the other of polythene. When the grain is put into the inner baft bag and the end is tied, the polythene end can then be folded on and tied after the air has been evacuated. This way, the insects use up the oxygen in the bag and are killed. The baft prevents insect larvae from piercing through the polythene which would destroy the airtightness of the bag.

Research at the Institute has confirmed that storing cowpea in pods in mud granaries provides adequate protection for the seeds within. Attention has now been focussed on selecting varieties of cowpea with pods which do not readily shatter and which are either not attractive to *C. maculatus* or do not permit the larvae to penetrate. The IAR also emphasizes cleanliness and good storage hygiene to store owners in order to reduce the reservoir of pests. Visits to farmers' stores as well as state stores and warehouses in northern Nigeria show that considerable losses occur through lack of storage hygiene. The various investigations and recommendations arising from the visits have led to a significant reduction in food grain losses in the northern states. As noted by Ayertey (1980), for sorghum, there has been a reduction of annual losses due to insect pests from 4% (Giles, 1964a) to 1.4% (Caswell, 1979).

Areas of Future Research and Possible Assistance from International Bodies

The Institute for Agricultural Research Samaru, is located in an ecological zone where sorghum and millet are grown and where maize and cowpea production is increasing. It has the infrastructure for work on post harvest technology. Support is needed in the following areas:

i. Apart from the work of Kalkat and Ohiagu (1982) on pre and harvest losses of sorghum, no comprehensive study has been carried out on the same crop from the farm to consumer. For a better understanding of postharvest process, it is necessary to assess losses at each stage.

ii It is vitally necessary to investigate the susceptibility of different varieties of good grain being developed by breeders to storage insects and moulds before they are released.

iii Designing and development of cheap harvesting and threshing/ shelling machines appropriate for use in the savanna zone.

iv The establishment of an extension unit solely concerned with the dissemination of appropriate post harvest technology must be our concern and assistance is needed in this area from international bodies interested in the development of packages of technology for preventing postharvest losses in the savanna zones.

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PART III

Soil and Water Management

28 Analysis of Rainfall Records and its Implications for Improving Rain-use Efficiency for Cereal Production in Niger

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Abstract Analysis of the daily rainfall records for selected stations in Niger was undertaken to quantify its variability and the related risks of seasonal drought and crop failure for cereal production. The most serious drought risk is due to the low, variable rainfall coupled with low depth per rain event, high atmospheric evaporative demand, and low water-retention capacity of the soils used for cereal production. These results suggest that the key to minimising these risks is manipulation of the soil and crop to conserve soil-moisture and improve rain-use efficiency. Attempts were made to identify parameters that would allow short-term forward predictability of the rainfall as the season advances. Preliminary results indicate that the midpoint of the rainy season has potential as a predictor.

Introduction

In common with their neighbours in sub-saharan West Africa, drought and the spectre of famine are common to the peoples of Niger. Between 80 to 90 per cent of the 6.5 million inhabitants of Niger are subsistence farmers cultivating about 5 million hectares annually for producing rainfed sorghum and millet. Irrigated agriculture still contributes very little to the total food production in Niger (Table 1). Most of the rainfed cultivation occurs south of the 300 mm isohyet which is considered as the northern limit of rainfed cereal production in Niger. (Figure 1). This zone, which is approximately 300,000 square kilometres in area has an ecoclimate that varies from arid to semi-arid to subhumid (Le Houerou and Popov, 1981). About 75 per cent of this zone is semi-arid. The estimated population density in this zone is over twice its potential supporting capacity when using low-input technology (Table 1). The need for improved practices is therefore recognised as urgent.

The total quantity of rainfall and its spatial and temporal distribution in Niger, profoundly affects the livelihood of the majority of the inhabitants of Niger. The rainfall behaviour by itself is however only one aspect of the drought problem. The soil serves as a storage reservoir for the rainfall from which crops meet their transpiration requirements between precipitation events. The availability of this stored water and the efficiency with which cereal crop plants utilise it are other aspects that are equally important. Whilst little can be done to change total rainfall or its distribution, the soils and crops are amenable to manipulation to increase efficiency of the

Table 1 Geographical data on Niger*

Population:	Total	6,500,000
	Nomadic	845,000
	Rural	4,810,000
Area in sq.km:	Total	1,246,556
	Desert	778,198
	Arid	262,046
	Semi-Arid	170,726
	Sub-Humid	33,586
Area South of 30 mm isohyet:	22.5% of total.	
Cropped area in 1985:	4,867,000 HA or 3.8% of total.	
Area cropped to cereals in 1985:	88.4% of cropped area.	
	millet	3,150,000 HA
	sorghum	1,200,000 HA
Irrigated area 1985: 11,000 HA		
Estimated persons/HA cropped area: 0.98		
Estimated persons/HA in combined semi-arid and subhumid zone: 0.23		
Estimated potential supporting capacity of combined semi-arid and sub-humid zone using low-input technology: 0.11 persons/HA**		
Estimated potential supporting capacity of combined semi-arid and sub-humid zone using intermediate technology: 0.43 persons/HA**		

* Source: Ministry of Agriculture, Niamey, Niger.
** Source: F.A.O. Plant Production and Protection Paper No. 31 – An ecoclimate classification of Intertropical Africa, 1981 by H.N. le Houerou and F.G. Popov.

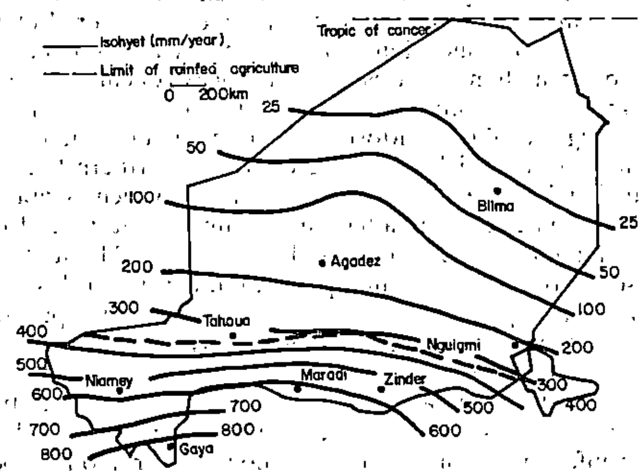

Figure 1 Map of Niger showing isohyets and limit of rainfed agriculture.

available rainwater, and thus optimise its use for cereal production. In order to develop rational methods for achieving this, the detailed interrelationship between the rainfall climate, the soil hydrological properties, and cereal crop phenology need to be studied and understood.

Over centuries of rainfed cereal production, farmers in Niger have evolved empirically-based strategies of soil and crop-management to suit their specific rainfall and adaphic environment. The most important characteristics of the unimodal, convective-type, monsoonal, rainfall over Niger are the low total annual depths being nowhere greater than 850 mm, and its high variability, unreliability, and unpredictability. A marked north/south rainfall gradient exists, associated with the gradual northward advance and retreat of the Inter Tropical Front (ITF); rainfall being possible only south of the ITF (Cocheme and Fanquin, 1967; D'Honneur, G., 1971; Ojo, 1977; Virmani *et al*, 1980). Most of the cereal producing soils have low natural productive potential from both the chemical and physical viewpoint. They are sandy, with a low-activity clay fraction and low available water-capacity (Ouattara and Persaud, 1985). The potential evaporative demand is high. Many of the traditional soil and crop management practices for cereals in Niger can be rationalised as adaptations to the overall rainfall and edaphic environment. Selection of long, medium, and short-cycle varieties of millet and sorghum, low stand densities, shallow cultivation for weed control, intercropping with legumes, natural water-harvesting, and recession farming are examples of traditional cereal production technologies well suited to the agroecological realities in Niger.

Traditional practices are not only an expression of the natural abiotic and biotic potential of the environment but also of historical factors. They were developed empirically and may not represent the optimal use of the environmental potential. To achieve an optimum requires rational technological changes which can ideally be grafted onto traditional practices. Given the socio-economic realities in Niger, these changes must have low-input or intermediate input requirements to be sustainable.

The development of such changes with respect to soil and water management for rainfed and irrigated crop production in the semi-arid tropics (SAT) form the main goal of TROPSOILS, acronym for a USAID-financed collaborative research program for soil management in the SAT. The primary research site for TROPSOILS' activities in the West African SAT, is Niger. Part of its program involved an indepth analysis of all available rainfall records in Niger with a view to orient research efforts in developing an appropriate and sustainable technological package of practices to optimise use of available rainfall.

This report discusses the results of specific aspects of these studies. The objectives were, firstly, to better quantify and understand the risks of seasonal drought associated with the variability and irregularity of the North/South monsoonal rainfall gradient over Niger, and secondly, if possible, find early season parameters that can serve as reasonably reliable indicators of overall and/or later-season rainfall in order to lessen its unpredictability.

Data and Analysis

The data consisted of available daily rainfall records for 85 stations that constitute the present rainguaging network in Niger, from their origin to 1983. Records for 80 of these stations from their origin to 1983 were compiled by ORSTOM (1966). The ORSTOM data-set, was updated to 1983. A set of 43 stations with 25 years or more of complete record were selected for use in the rainfall analysis study. These stations are shown in Figure 2, and represent a sparse network. The most northern station is Iferouane with North Latitutde 19°05′ and the most southern is Gaya with North Latitude 11°59′. The mean annual rainfall for these two stations is 58.4 and 830.7 mm respectively a decrease of 1.8 mm per minute increase in latitude, equivalent to 1 mm per km. The numbers in parenthesis next to the staton names in Figure 2 are the original identification codes used in the ORSTOM compilation. Various techniques were used to analyse the data and these will be discussed below.

Results and Discussion

Simple statistics were calculated for each decadal total between May 1 and October 31, over the years of complete record for all 43 stations. Table 2 shows the results for 4 stations Gaya, Niamey, Tahoua, and Agadez, along the North/South rainfall gradient. They show that nowhere is the coefficient of variation (CV) less than 50 per cent. For all decades the C.V. increases with increasing latitude. It is higher at the beginning and end of the season for all stations. These results underline the variability of the convective monsoonal rainfall over Niger.

Table 2 Mean decadal rainfall and coefficient of variation for 4 stations in Niger.

		Mean decadal value $\bar{X}$ mm and coefficient of variation C%							
		Gaya		Niamey		Tahoua		Agadez	
Month	Decade	$\bar{X}$	C	$\bar{X}$	C	$\bar{X}$	C	$\bar{X}$	C
May	1	14.3	124	3.8	224	2.4	238	0.6	367
	2	16.1	101	10.3	122	3.8	180	1.1	283
	3	37.5	98	20.5	134	9.3	143	4.1	269
June	1	34.2	81	22.0	95	16.3	125	1.6	258
	2	44.6	71	29.7	91	15.8	121	3.0	272
	3	40.0	72	27.2	65	20.3	88	4.4	165
July	1	54.5	66	36.8	59	25.0	79	4.1	162
	2	57.7	64	55.0	56	37.1	76	11.6	101
	3	77.3	60	69.0	65	48.3	67	25.5	84
August	1	86.5	51	57.8	65	42.9	65	26.7	97
	2	83.9	56	66.0	58	50.1	68	29.9	84
	3	88.0	62	68.4	71	43.6	69	19.3	91
Sept.	1	70.2	62	49.1	73	26.8	71	7.3	142
	2	51.4	56	34.3	79	19.4	84	4.6	224
	3	33.7	76	13.8	93	10.7	119	1.6	277
Oct.	1	11.4	120	7.4	143	4.9	181	0.12	440
	2	4.7	206	4.0	251	5.3	254	0.14	465
	3	3.3	376	1.8	208	0.6	744	0.02	794
N. Lat.		11°59'		13°29'		14°54'		16°59'	
Years record		53		41		59		63	
Mean annual rainfall		830.7		585.3		387.4		147.5	

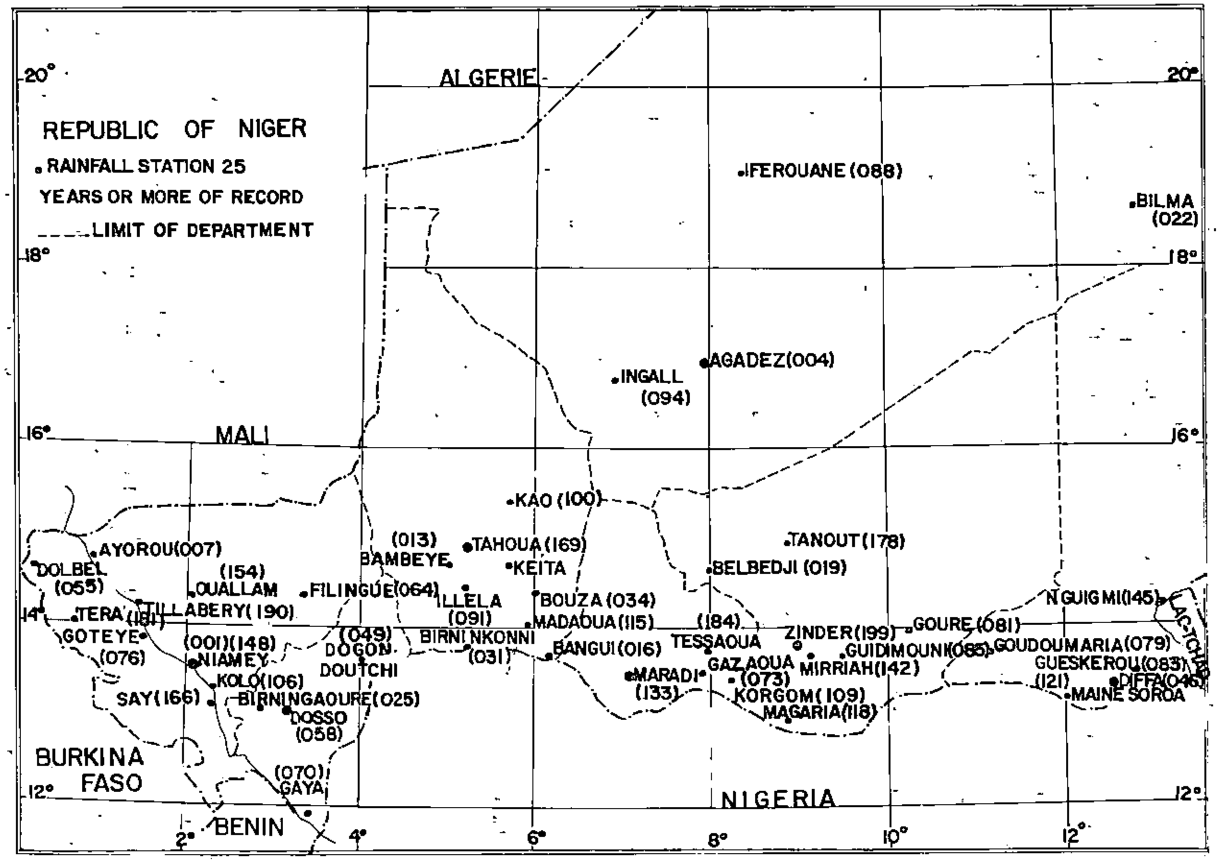

Figure 2 Network of rainguaging stations in Niger with 25 years or more of complete record.

Counting probabilities were calculated for all 43 stations to obtain the probability of receiving at least certain specified decadal totals during the rainy season (Persaud *et al.* 1986). Table 3 shows the partial results for 3 stations with increasing North Latitude within the zone of feasible rainfed cereal production. These results illustrate the general patterns obtained from the results for all 43 stations. For a specified decadal, total probability decreases with increasing north latitude. This decrease is more rapid with the higher specified total. For all specified totals the probabilities increase regularly with the season to a maximum and then decrease. The increasing phase is more gradual, and the decreasing phase more rapid, since the advance of the ITF over West Africa is slower than its retreat (Ojo, 1977).

Table 3 Probabilities (per cent) of receiving at least the specified decade totals for 3 stations in Niger from May through September.

Month	Decade	10 mm			20 mm			40 mm		
		1	2	3	1	2	3	1	2	3
May	1	49	12	6	26	4	3	9	2	0
	2	56	39	15	32	19	5	9	2	0
	3	81	58	32	58	34	15	35	19	5
June	1	84	60	45	67	39	25	35	26	11
	2	88	75	54	77	48	27	47	26	8
	3	92	82	61	77	63	38	37	14	16
July	1	94	92	71	75	82	50	60	36	22
	2	86	95	89	81	87	72	66	70	35
	3	96	100	96	92	87	81	79	70	57
August	1	98	92	93	96	92	74	84	63	47
	2	100	97	93	100	95	81	83	70	52
	3	98	95	91	98	92	79	83	65	44
Sept.	1	98	92	79	90	85	57	75	46	25
	2	92	78	57	83	65	38	62	36	11
	3	77	53	44	64	29	20	35	4	3

1: Gaya (11°59'N.Lat); 2: Niamey aerodrome (13°29' N.Lat.); 3: Tahoua (14°54'N.Lat)

The counting probabililty results can be used to obtain estimates of periods within which a given level of probability for a specified total was exceeded. Table 4 presents the estimates obtained using Table 3. The length of the period in days with 50% and 75% or more probability of receiving decadal totals of 10, 20, and 40 mm decrease rapidly with increasing north latitude and with increasing totals. The potential evapotranspiration (PET) anywhere in Niger exceeds 4 mm per day and the shortest cycle for cereal crops is 70-80 days. Table 4 indicates that there is a high risk of drought and total crop failure is very high.

In order to precisely define the drought risk with increasing latitude in relation to PET parametric statistical methods were utilised. Incomplete gamma probability density distributions were fitted to the decadal rainfall totals for all stations with 40 years or more of complete record. Table 5 gives the parameters of the fitted density distributions for Gaya, Niamey,

Table 4 Period in days with 50 and 75 per cent or more probability of receiving at least 10, 20, or 40 mm of rain. Dates for 50 and 75 per cent probabilities obtained by linear interpolation in Table 3.

	PERIOD IN DAYS WITH					
	50% or more probability of receiving at least			75% or more probability of receiving at least		
Station	10mm	20mm	40mm	10mm	20mm	40mm
Gaya	157	136	88	133	106	54
Niamey	135	102	63	101	78	0
Tahoua	110	74	35	69	46	0

and Tahoua. The techniques for fitting the density distributions to the sample frequency histograms were taken from Haan (1977). Table 5 shows the increasing skewness of the distributions, as indicated by the departure of the coefficient of skew from unity, with increasing north latitude. The skewness is greater early and late in the season whereas the mid season decadal totals are more normally distributed. These density distributions were integrated numerically (Henrici, 1977) to yield cumulative distribution functions which were then used to generate rainfall depths corresponding to the levels of exceedance probability of 0.25, 0.50, and 0.75. Mean decadal PET by Penman's method as modified by F.A.O. were calculated for 11 stations each with 9 years of data from 1971-1979 inclusive (Frere and Popov, 1979). The mean PET values by decade from May to October for Gaya, Niamey, and Tahoua are given in Table 6, which gives a quantitative appreciation of the high evaporative demand during the rainy season in Niger. The calculated rainfall depths for each level of exceedance probability for these three stations are plotted in Figure 3. Before plotting, these values were smoothed using a Fourier series with two terms. The values of 0.5 PET and 0.35 PET for each decade are also plotted in Figure 3. Before plotting these values were also smoothed using a three-point moving average and the weights 1:2:1. The period in which rainfall exceeds 0.5 PET or 0.35 PET is used as definitions of growing period that is free from stress (Cocheme and Franquin, 1967; Le Houerou and Popov, 1981). Using these definitions the resulting growing periods were calculated and are presented in Table 7 for the three stations and for the three levels of exceedance probability. For a shortest possible growing period of 75-80 days it is clear from Table 7 that an adequate growing period at all three stations can be achieved in only 25 years out of 100. Crop failure is possible 50 years out of 100 north of Niamey based on the ≥ 0.5 PET definition.

The availability of the rainwater for transpiration after infiltration is another important factor in the overall drought risk problem. Most cereal producing soils in Niger have a water-retention capacity under free drainage of 10-12 per cent (Hartmann and Gandah, 1982). Heavy showers are expected to infiltrate deeper and there should be relatively less loss to evaporation than light showers. This loss is a function also of the frequency of the rainshower events. Table 8 shows the probabilities of receiving in a

Table 5 Parameters from fitting of the incomplete gamma density distribution to decadal rainfall totals for 3 stations in Niger.

		Gaya			Niamey			Tahoua		
Month	Decade	n	1/B	y	n	B	y	n	B	y
May	1	1.16	17.19	1.86	0.72	9.74	2.36	0.72	7.18	2.36
	2	1.41	13.43	1.68	1.00	13.27	2.00	0.95	7.88	2.05
	3	1.50	24.63	1.63	0.78	20.04	2.26	0.91	13.21	2.10
June	1	2.64	14.02	1.23	0.97	24.55	2.03	0.95	19.41	2.05
	2	4.14	11.64	0.98	1.23	24.67	1.80	1.13	15.29	1.88
	3	3.13	13.02	1.13	3.20	8.94	1.12	1.09	19.18	1.92
July	1	1.97	27.67	1.42	3.13	11.77	1.13	1.47	17.28	1.65
	2	2.39	24.64	1.29	5.12	10.75	0.88	2.15	17.29	1.36
	3	4.14	17.97	0.98	3.51	18.14	1.07	2.85	16.09	1.18
August	1	6.05	14.30	0.81	3.60	16.05	1.05	3.21	13.61	1.12
	2	7.93	10.57	0.71	5.12	12.91	0.88	2.98	17.09	1.16
	3	4.26	19.20	0.97	2.15	27.78	1.36	2.82	13.99	1.19
Sept.	1	4.65	15.40	0.93	3.42	14.35	1.08	2.38	11.82	1.30
	2	4.14	12.65	0.98	1.41	25.02	1.68	1.57	13.01	1.60
	3	2.26	16.14	1.33	1.10	12.84	1.91	1.21	11.60	1.82
Oct.	1	1.79	9.64	1.49	1.00	11.27	2.00	0.84	10.75	2.18
	2	1.10	11.96	1.91	1.03	12.24	1.97	0.73	22.68	2.34
	3	0.73	18.99	2.34	1.29	4.80	1.76	-	-	-

n: shape parameter; B: scale parameter; y: coefficient of skew ($2/\sqrt{n}$)

Table 6 Mean decadal potential evapotranspiration (PET) estimated by Penman's method using data from 1971-1978 inclusive for three stations in Niger.

		MEAN DECADAL PET IN MM		
Month	Decade	GAYA	NIAMEY	TAHOUA
May	1	67.7	76.1	70.1
	2	63.4	77.6	70.6
	3	66.6	84.1	73.9
June	1	56.1	72.4	66.7
	2	55.4	69.2	66.4
	3	53.2	64.6	61.5
July	1	48.1	61.2	53.8
	2	46.1	57.8	52.8
	3	47.9	60.0	56.5
August	1	42.9	55.4	50.6
	2	40.6	52.7	49.4
	3	45.6	59.6	55.8
Sept.	1	43.0	57.7	52.2
	2	43.5	57.8	54.2
	3	45.7	59.7	57.9
Oct.	1	47.3	59.1	59.5
	2	47.9	55.9	58.0
	3	54.2	67.6	62.8
Overall mean		50.8	63.8	59.6

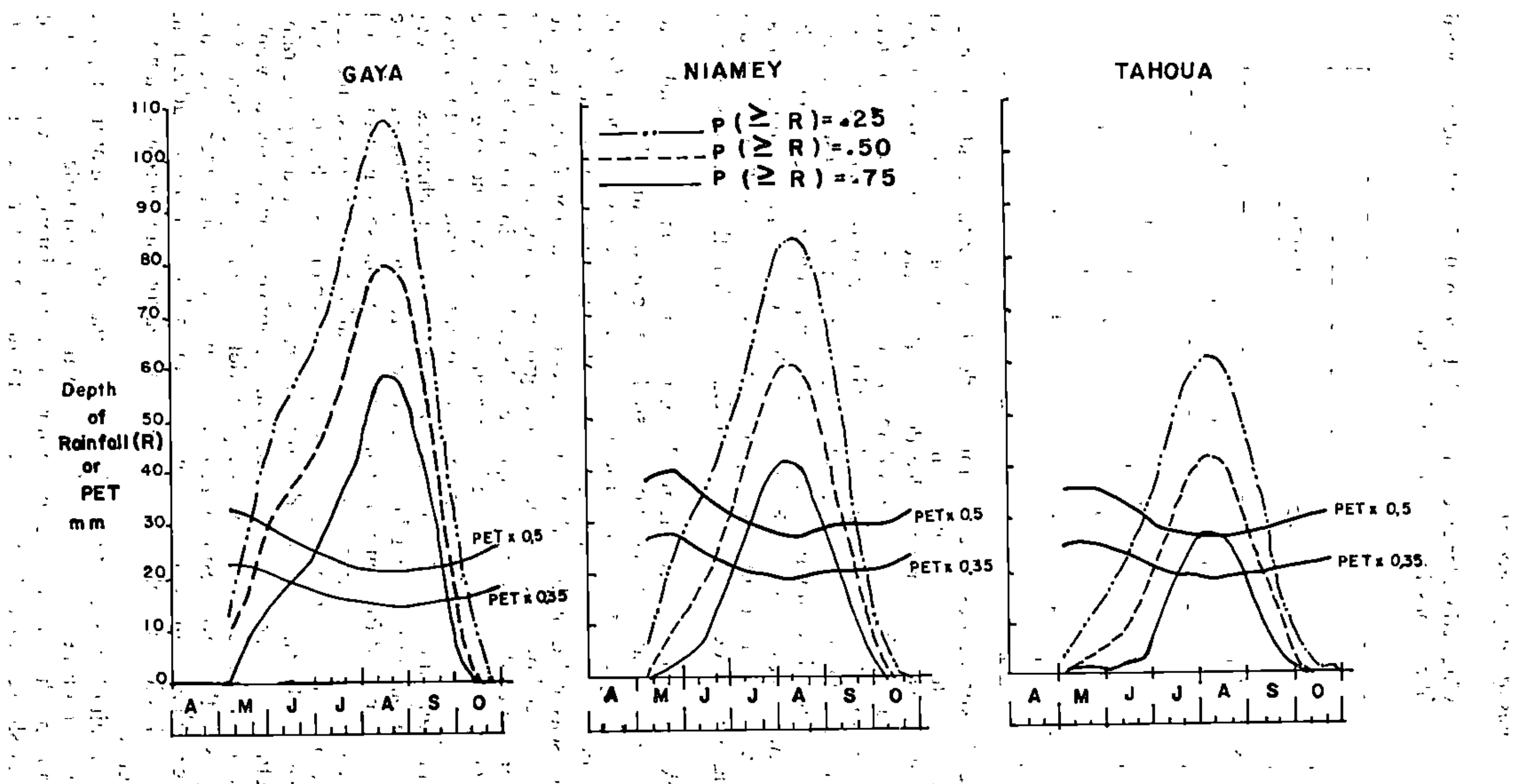

Figure 3. Length of the growing period based on PET/rainfall relationships for various levels of exceedance probability for 3 stations in Niger.

Table 7 Growing periods for exceedance probabilities of 0.75, 0.50, and 0.25 based on PET/rainfall relationships for 3 stations in Niger.

Exceedance probability	Growing period in days based on					
	Rainfall ≥ 0.5 PET			Rainfall ≥ 0.35 PET		
	Gaya	Niamey	Tahoua	Gaya	Niamey	Tahoua
0.25	136	94	78	184	116	94
0.50	116	74	52	140	90	66
0.75	80	48	14	82	64	40

single shower various specified rainfall depths for each decade for three stations in Niger. These probabilities are based on the total number of rainfall events for a particular decade over the entire years of record. For decades where this total was less than 30 probabilities were not calculated. Table 9 shows the average and median values of raindepth per rainevent for each decade during the same period for the 3 stations. Only those years with rain were used in computing these averaged and median values. The results in the two tables taken together show that heavy showers are rare and that the highest mean and median depth per rainevent is only 20.6 and occurs during the first decade of August for Gaya which is the wettest station in Niger.

Taken in their entirety, the results of the rainfall analysis undertaken to fulfill the first stated objective of this study, serve to quantify the variability and overall pattern of this variability as influenced by the north/south oscillation of the ITF over West Africa. They also underline the constant risk of seasonal drought and the high risks of rainfed crop failure that are annually faced over the lifetime of cereal growers in Niger. From Figure 3 it is clear that the key to minimising these risks is the manipulation of both soil and crop. Soil-water conservation practices that can increase rain-use efficiency and help maintain optimal soil moisture regimes under the highly variable rainfall climate are of paramount importance. Techniques of water harvesting can possibly lengthen the effective growing period by making use of low depths and frequency of rainevents early in the season (Tables 8 and 9). Reducing evaporation from bare soil surfaces by residues, reduced tillage, intercrops, timely weed control, judicious biomass reduction etc. will increase total transpiration and also thus increase yields and improve rain-use efficiency. Increased transpiration and a longer growing season would allow longer cycle varieties with higher yield potential to be grown. It is recognised that crop residues have alternative uses for fodder, fuel, and cottage industry in Niger. To these traditional uses must be added an additional role, that of soil moisture conservation and increased rain-use efficiency.

In pursuit of the second objective stated in the introduction of this report, various approaches were tried. Several of these showed little promise and did not produce a reliable predictor. However, interviews with cereal farmers showed that about mid season in July they were usually able to

Table 8 Probability of receiving various rainfall amounts in a single shower during each decade of May/June for 3 stations in Niger.

Month	Decade	Probability (per cent) of receiving in a single shower								
		$\geqslant$10 mm			$\geqslant$ 20 mm			$\geqslant$ 30 mm		
		1	2	3	1	2	3	1	2	3
May	1	36	8	12	12	5	6	6	0	3
	2	37	33	16	13	13	4	4	2	2
	3	47	29	19	26	13	7	18	9	3
June	1	50	25	25	30	14	10	17	6	4
	2	53	38	23	28	20	10	11	11	3
	3	54	33	22	28	16	9	9	6	4
July	1	55	42	29	29	20	11	14	10	4
	2	55	45	35	31	27	18	16	15	9
	3	60	40	40	36	23	17	21	13	8
August	1	57	38	40	33	22	18	24	10	9
	2	57	41	43	34	24	17	19	11	8
	3	55	38	35	35	20	12	20	13	6
Sept.	1	54	39	33	30	20	11	16	10	3
	2	46	38	23	25	17	8	9	6	3
	3	49	26	21	27	18	10	12	2	1
Oct.	1	40	26	13	11	6	7	3	2	2
	2	37	26	-	17	4	-	4	4	-
	3	26	12	-	16	0	-	0	0	-

1: Gaya (11°59'N) ; 2: Niamey (13°29'N) ; 3: Tahoua (14°54'N)

Table 9 Overall mean and median values of depth per rain event for each decade from May to October for three stations in Niger considering only rainy years in each case.

Month	Decade	Overall mean (X) and median (m) values of depth per rain event for rainy years (n)								
		Gaya			Niamey			Tahoua		
		X	m	n	X	m	n	X	m	n
May	1	9.4	7.3	37	3.5	1.9	22	4.0	1.9	28
	2	9.8	8.7	45	8.4	6.8	32	4.9	2.3	30
	3	14.0	11.6	49	8.8	6.8	37	5.5	3.6	45
June	1	15.9	15.1	49	7.6	7.5	38	7.7	6.0	52
	2	14.9	14.0	49	12.8	10.4	40	7.2	4.9	54
	3	14.3	12.2	51	10.5	8.0	39	6.6	6.1	57
July	1	15.0	14.3	53	13.9	10.3	41	8.1	7.4	58
	2	19.5	15.3	52	14.0	14.2	41	10.6	8.0	59
	3	20.0	19.6	52	12.4	10.5	41	11.2	10.6	59
August	1	20.6	19.1	53	12.2	11.6	41	11.2	10.2	58
	2	20.4	18.2	53	13.1	12.8	41	11.7	10.2	58
	3	20.3	16.1	53	12.5	12.4	41	11.7	10.2	58
Sept.	1	16.0	16.2	52	11.7	10.4	41	9.1	7.9	59
	2	14.3	13.6	52	9.4	8.6	40	7.5	6.6	56
	3	15.1	13.6	49	7.5	5.2	40	7.3	5.0	45
Oct.	1	9.5	8.0	35	6.8	4.5	27	4.6	3.4	32
	2	9.7	7.6	19	6.9	3.9	13	11.1	5.2	19
	3	6.9	4.7	12	4.8	4.2	12	—	-	-

judge with some confidence the general outcome of the season by the rainfall behaviour. To quantify this empirical perception, for each year of data for a given station partial rainfall totals were calculated by truncating the series one week at a time forwards from January 1 and backwards from December 31. The partial sums were expressed as percentages of the total for the year and plotted as illustrated in Figure 4, which provides an example of this procedure for one year of the records for Gaya. The two curves in Figure 4 are inverted mirror images of each other and cross the 50% line at a common point. This point defines the mid point of the season for that year. From a diagram such as Figure 4 other information besides the midpoint can be obtained. Thus the beginning, end, and length of period corresponding to a given percentage of the total rainfall for the year can easily be read of these curves. Windows centrally or asymmetrically located with respect to the beginning and ending dates of the rainy season and corresponding to various percentages of the total rainfall can also be obtained, from these curves. All these parameters would change from year to year for a particular station.

It was decided to examine more closely the behaviour of the midpoint of the season for its usefulness as a predictor although any other point

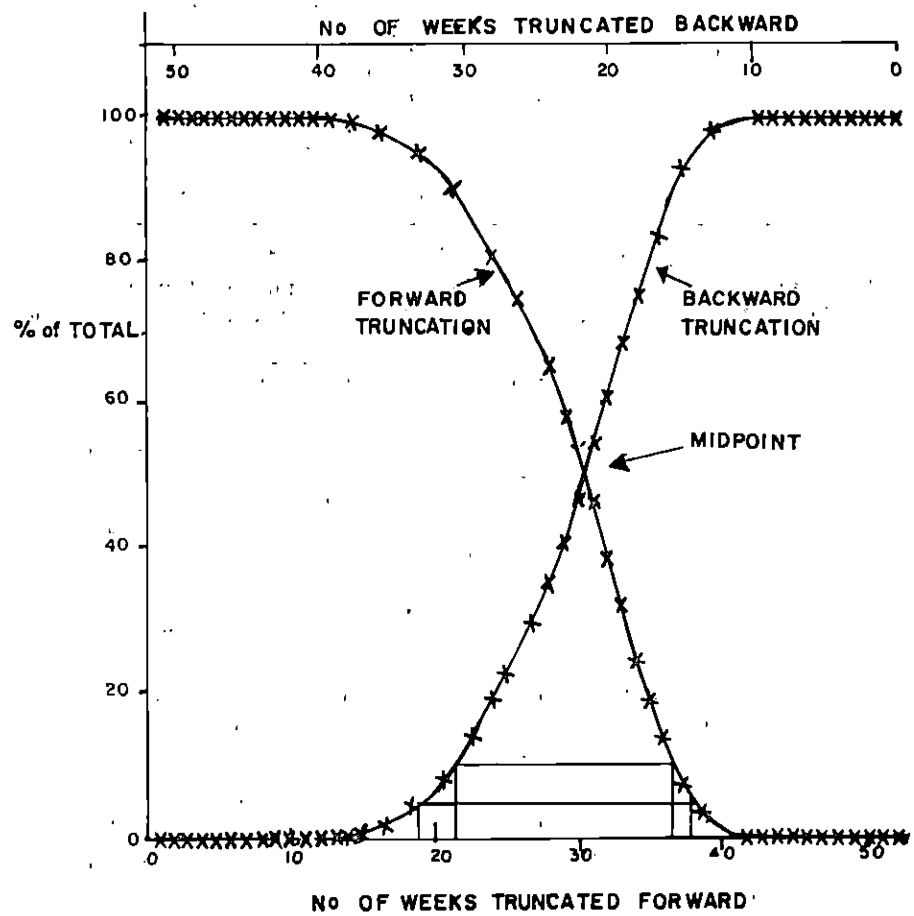

Figure 4 Example illustration forward and backward truncation technique to determine midpoint and other parameters, of the rainy season.

representing a particular percentage could have been chosen. If the date of the midpoint varied little in the historical record it would enable the conclusion that once this date was reached in any year for a given station the amount of rainfall likely to occur after this date would be the same as that already obtained prior to this date. Table 10 shows the statistics of the computed annual midpoints expressed as weeks from January 1 for three stations in Niger. It is clear that the mean midpoint did not vary much with change in latitude of the stations. Also the variability was relatively low. Thus at any date within the window defined by $\bar{X} + S$ and $\bar{X} - S$ (Table 10) there is about 60% confidence that the rainfall for the remainder of the season will be the same as that obtained prior to this date. Further studies on this are in progress but preliminary indications are that this technique may help to provide some measure of predictability of the rainfall patterns over Niger. This would help in making calculated decisions on management options early in the season and can possibly reduce the risk of crop failure. These results also substantiate the empirical perceptions of cereal farmers.

Table 10. Statistics of the annual midpoints of the rainy season in weeks from January 1 for 3 stations in Niger.

	S T A T I O N		
Statistic	Gaya	Niamey	Tahoua
Mean, $\bar{X}$	30.3	30.4	30.4
Standard deviation, S	1.3	1.3	1.5
Total years	53	41	59
No. values between $\bar{X} + S$ and $\bar{X} - S$	37	26	40
% of total	70	63	68

In conclusion rainfall analysis can provide valuable quantitative insight into generalised rainfall patterns and constraints, risks of crop failure, and predictability. As stated in the introduction this knowledge helps in orienting research into practices to minimise these risks for rainfed cereal production in Niger. The most promising results can come from research into practices that can conserve soil moisture and increase rain-use efficiency. Research within the TROPSOILS semi-arid tropics program is currently focussed in this area.

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29 Rainfall Characteristics at Selected Sites in Burkina Faso

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Abstract Semi-Arid West Africa has been experiencing severe crop yield losses due to poorly distributed and/or reduced rainfall since 1967. Yield losses could be minimized if rainfall characteristics, particularly the predictable ones (viz. rainfall partitioning and the occurence of dry spells for each month of the crop season), were known. Such knowledge can be useful in developing new cultivars and crop production practices adapted to changing climatic conditions. Studies which have dealt with rainfall characteristics on a monthly basis, were supplemented with data based on 5 days and the occurence of 8, 10, 15, 20 and 25 days dry spells for each month of the crop season. The adaptation of maize and/or cowpea to each of the major agroclimatic zones in the semi-arid West Africa is discussed.

Introduction

Rainfall is a major source of available soil moisture under rainfed crop production in semi-arid West Africa. Since 1967, this region has been experiencing poorly distributed and/or insufficient rainfall (Cochème and Franquin 1967, Posner *et al.* 1985, Traore and Monnier 1980). Together with the use of agricultural husbandries and crop varieties, which are no longer adapted to changing climatic conditions, this has resulted in severe yield losses.

Rainfall of a given area may be considered to have two characteristics: one predictable and the other unpredictable. The predictable characteristic consists of months or periods of a month, i.e. 5, 10, etc days which are likely to receive rains. The unpredictable characteristic consists of actual rainfall received in a month or in a period of one month and its year to year variation.

Predictable rainfall characteristics of an area may be a useful tool in effective crop management by farmers and crop improvement by breeders and agronomists. Farmers may use them for planning and timely execution of crucial cultural practices (viz. proper choice of crop varieties, land preparation, dates of planting etc). Crop breeders may use them for determining suitable cultivar maturity groups and crop growth stages where drought is likely to occur; they can thus concentrate their efforts on those growth stages to breed for drought resistance or tolerance. Agronomists may use them to devise new crop production practices, which can reduce drought damage.

Rainfall characteristics in West Africa and Burkina Faso have been studied by Virmani *et al.* (1980) and French scientists (Boulet 1976, Cochème and Franquin 1967, Peron and Zalacain 1975). Virmani *et al.* (1980) computed dependable rainfall for each month. Dependable rainfall of a month compared to potential evapotranspiration (PET) of that month would help to determine whether it is dry or rainy or a transition. French studies using a graphic method developed by Cochème and Franquin (1980) grouped a year into four periods (viz. first transition, rainy, second transition and dry periods). These studies do not, however, provide information on rainfall partitioning and occurence of dry spells for each month of the crop season. A study of rainfall partitioning was therefore undertaken based on 5 days and computed frequencies of occurence of 8, 10, 15, 20 and 25 day dry spells for each month of crop season, at five selected sites in Burkina Faso, in order to provide a simple and easy to use model for studying rainfall characteristics within inter-tropical regions (between 9 and 18° latitude).

Materials and Methods

Rainfall data, read at 8:00 hr a.m. every day for the 20 year period 1961 to 1980, were obtained from the National Meteorological Service of Burkina Faso, ASECNA (Agence de Sécurité pour la Navigation Aérienne en Afrique et au Madagascar) for five selected locations shown on an isohyet map (Fig. 1). The locations were: Farako-Bâ (lat. 1106, long. 04 23, alt. 405 m), in Northern Guinea Savanna; Saria/Koudougou (lat. 12 16, long. 02 22, alt. 250 m), Kamboinsé (lat. 12 28, long. 01, 33, alt. 300 m) and Fada N'Gourma (lat. 12 04, long. 00 21, alt. 292 m), in Sudan Savanna; and Gorom-Gorom (lat. 14 27, long. 00 14, alt. 380 m) in the Sahel.

Cochème and Franquin (1976) considered plant growth to take place if a crop received rainfall equal to or greater than 50% potential evapotranspiration (PET), assuming that a soil water reservoir had been established by a rainy period receiving 100 mm rainfall. Using the same concepts a rainy day or five day period was considered as one that received rainfall equal to or greater than 75% PET; and a dry spell, as one in which none of the constituent days was rainy; or if it were, it would not have any impact on plant growth because the preceding and following periods were too dry. Based on the 20 year rainfall data, the frequency (expressed in percentage) with which a given 5 day period for each month of the crop season was rainy was computed. Similarly, the frequency of dry spells of 8, 10, 15, 20 and 25 consecutive dry days for each month of crop season was also computed. These frequencies can also be viewed as the probability with which a given period is likely to be rainy. Dividing 100 by a given frequency, an idea of how often a given five day period was rainy in a certain number of years (for instance: frequencies of 15% and 75% mean, respectively, one out of every six to seven years and 3 out of every 4 years) was obtained. PET data used were obtained from Virmani *et al.* (1980).

Results

Farako-Bâ in Northern Guinea Savanna

Rains are well distributed and reliable from July 15 to September 20 (Fig. 2). They tended to be poorly distributed from the end of May to July 15 and towards the end of September. During these periods, 8 and 10 day dry spells were experienced with frequencies varying from 10 and 5% in July, to 45 and 20% in June, respectively. Rains were poorly distributed in May and October. Both these months can experience 8 and 10 day dry spells 3 out of every 4 years; they can also experience 25 day dry spell one out of

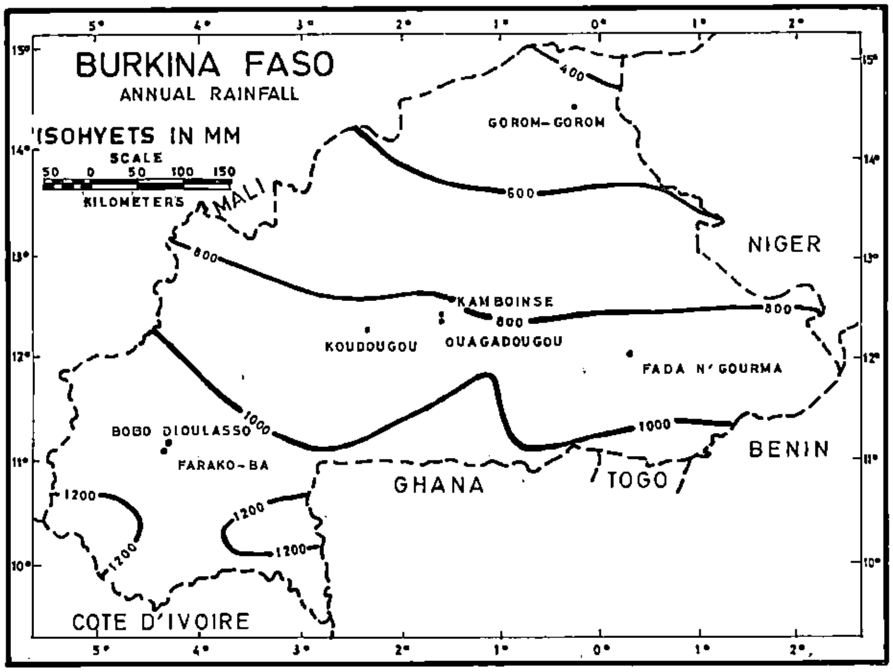

Figure 1 Isohet map of Burkina Faso.

every 7 to 10 years. Drought is, thus, more likely to cause damage to a May planted crop, or a crop that fills its grains in October.

From an agricultural standpoint, May 1 to June 10 appeared suitable for land preparation; June 10 to mid-July, for sowing; mid-July to September 20, for active growth (viz. vegetative, flowering, fertilization and grain filling growth stages); and September 20 to October end, for maturation and harvesting.

Kamboinsé, Saria, Fada N'Gourma in Sudan Savanna

Rains tend to be well distributed and reliable from mid-July to mid-September at the three Sudan savanna locations (Fig. 3). They are poorly distributed from June 1st to mid-July and in late-September. This is well illustrated by increased frequencies of dry spells, particularly for 8 day dry spell, for those periods (Fig. 3). Saria, however, distinguished itself from the other two locations by tending to have low frequencies of dry spells in July and September. Like the situation of Farako-Bâ, rains are very poorly distributed in May and October. Both months present high risk for severe droughts.

From an agricultural standpoint, crop calendar is not different in Sudan savanna compared to northern Guinea savanna. However, owing to poor distribution of rains in June, early-July and late September in Sudan savanna, crop varieties used in that climatic zone will have to be more drought resistant, particularly during vegetative and grain filling growth stages, than in northern Guinea savanna.

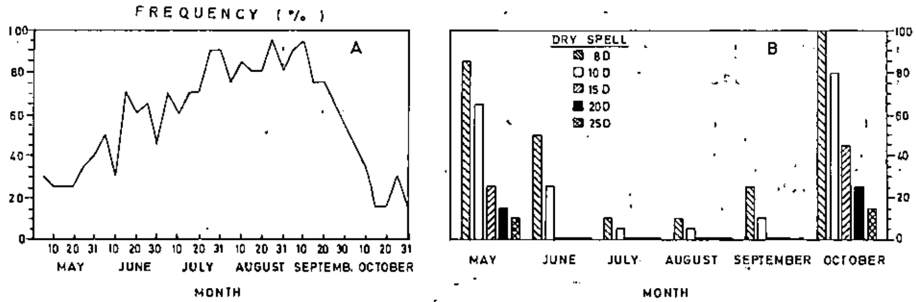

Figure 2 Frequency of rainy periods on 5 day basis (A) and 8, 10, 15, 20 and 25 day dry spells (B) at Farko-Bâ, Burkina Faso, from 1961 to 1980.

Table 1 Rainfall characteristics at Farako-Bâ, Kamboinsé, Saria, Fada N'Gourma and Gorom-Gorom (extracted from Virmani et al. 1980).

Locations		May	June	July	August	September	October
					mm		
Farako-Bâ	r	106	141	207	277	205	58
	dr	69	111	137	227	165	21
	PET	162	131	123	116	117	137
Kamboinsé	r	63	125	177	246	156	38
	dr	39	92	141	196	118	10
	PET	190	151	135	113	121	149
Saria/ Koudougou	r	66	111	182	263	172	46
	dr	37	77	136	205	126	20
	PET	185	145	132	114	119	144
Fada N'Gourma	r	78	125	185	267	165	27
	dr	49	95	141	217	119	7
	PET	192	162	136	113	123	150
Gorom-Gorom	r	17	72	124	174	76	8
	dr	5	32	92	131	54	2
	PET	218	208	179	145	144	169

r = rainfall;
dr = dependable rainfall;
PET = potential evapotranspiration.

Gorom-Gorom in the Sahel

Rains were poorly distributed and less reliable for each month of the crop season at this Sahelian location (Fig. 4). May and October were too dry and had high frequencies of 25 days dry spells, and therefore cannot be considered as part of crop season. June up to mid-July and September are high drought risky periods. Eight and 10 day dry spells are frequently observed during crop season even in August (Fig. 4).

From an agricultural standpoint, June to early July appeared suitable for land preparation; early to mid-July, for sowing; August to early-September, for active growth; and mid-September to early-October, for maturation and

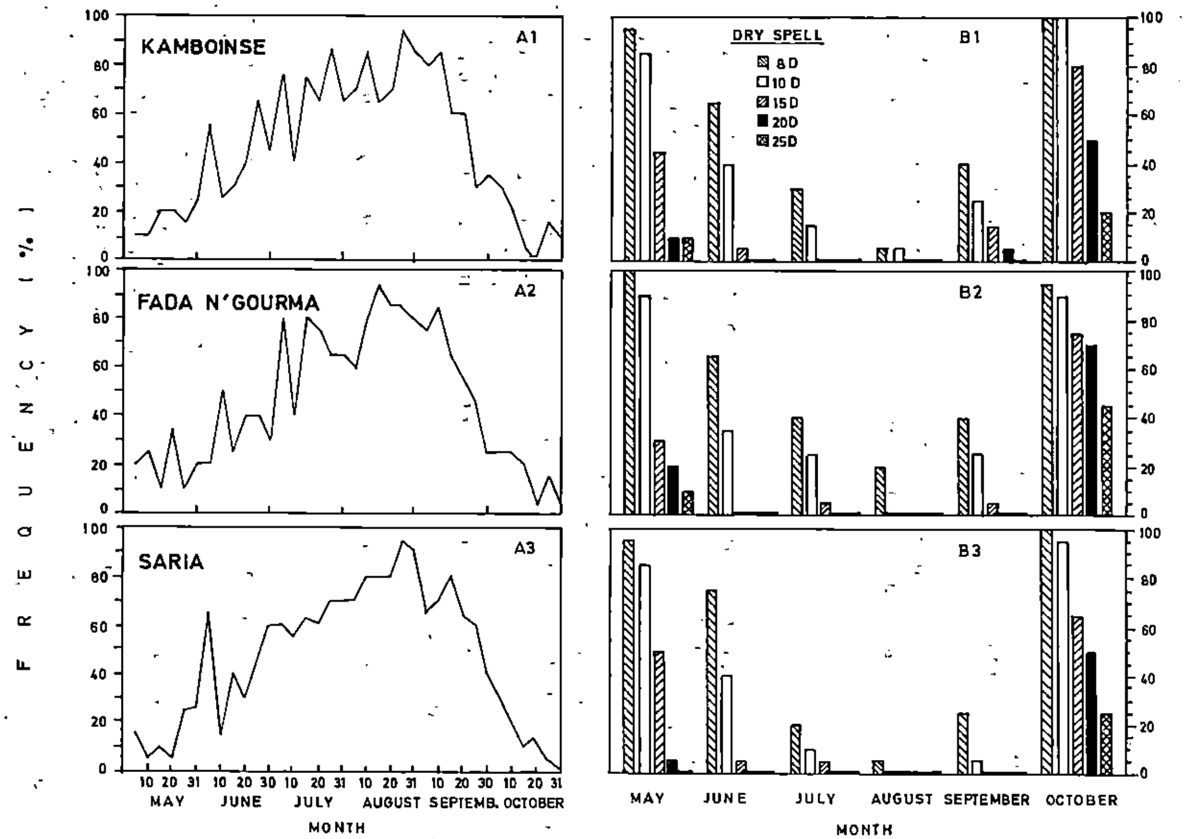

Figure 3 Frequency of rainy periods on 5 day basis (A) and 8, 10, 15, 20 and 25 day dry spells (B) at Kamboinse, Fada N'Gourma and Saria, Burkina Faso, for 1961 to 1980.

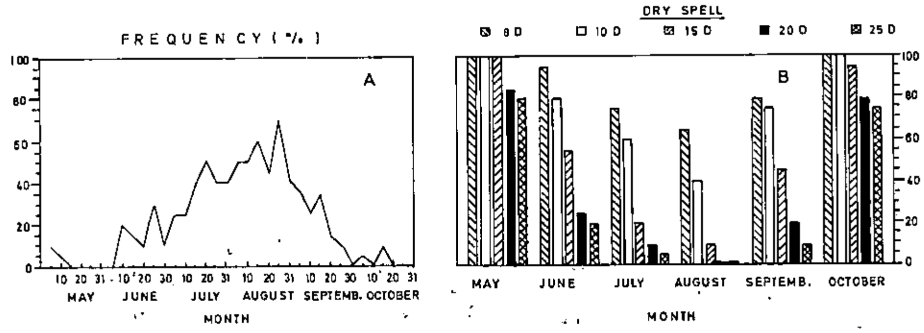

Figure 4 Frequency of rainy periods on 5 day basis (A) and 8, 10, 15, 20 and 25 day dry spells (B) at Gorom-Gorom, Burkina Faso, from 1961 to 1980.

harvesting. The crop season is, thus, much shorter and requires the use of more drought resistant (at all growth stages) crop varieties than in Sudan savanna.

Discussion

By narrowing the rainy period from 30 days to 5, it was possible to identify rainy months (frequency greater than 70%) from transition (frequency between 40 and 70%) and dry (frequency less than 40%) months. These findings were in agreement with those of Virmani *et al.* (1980). In addition, it was possible to study the rainfall partitioning and identify, for each month of the crop season, periods which were likely to experience dry spells. The frequency and duration of dry spells provided for each month would give farmers, crop breeders and agronomists an idea about droughts and crop growth stages at which they are likely to occur. They can thus take appropriate measures through either genetic or environmental manipulations or both to reduce drought damages.

Implication for Maize [*Zea mays* (L.)] and Cowpea [*Vigna unguiculata* (L.) Walp.] Production

Maize

Maize is highly and less sensitive, respectively, to soil moisture stress during generative growth (15 to 21 days before and 35 to 45 days after flowering) and vegetative growth stages (Stegman 1982). Therefore, 105 days maturing maize cultivars sown between June 10 and 20, would flower by early-August and complete its grain filling by mid-September. Such maize would suffer less from drought stress at Farako-Bâ, in northern Guinea savanna, than at locations in Sudan savanna, where it can be exposed to 15 day dry spells in June and September (and even to 20 day dry spell in September) at Kamboinsé, July and September at Fada N'Gourma, and June and July at Saria (Figs 2, 3). A 90 days maturing maize sown in late June would flower and reach maturity at the same time as 105 days maize planted between June 10 and 20. It would escape drought stress in June. Maize crop therefore requires more genetic and environmental manipulations to reduce drought damages in the Sudan than in northern Guinea savanna.

For the Sahel, the crop seaon is too short and rainfall too erratic for a good maize crop. Perhaps, special genetic and environmental manipulations are required to insure some acceptable maize seed yield in this environment.

Cowpea

Like maize, cowpea is highly and less sensitive to drought stress during generative (slightly after flower bud initiation to grain filling) and vegetative growth stages, respectively (Turk *et al.* 1980, Ziska and Hall 1983a, 1983b). However, cowpea is more drought resistant and has a much shorter growth cycle (60 to 90 days) than maize. Different types and growth cycles have been identified in cowpea: extra-early (55 to 60 days to maturity) and intermediate (75 to 90 days) both daylength-insensitive cowpeas; and early, intermediate, and late maturing daylength-sensitive cowpeas requiring critical photoperiod of respectively, 12:30 hr (late August), 12:00 hr (late September) and less than 12:00 hr (mid-October) to flower. Extra-early and intermediate maturing daylength-insensitive cowpeas sown from June 10 to 30 at Farako-Bâ or in Sudan savanna would mature in early to late August. They would be subjected to seed rotting due to protracted rainy periods at that time of the year, whereas the same cultivars planted in mid-July would mature in late September to early October and experience less seed rotting although they can be subjected to drought, which may be severe in Sudan savanna (up to 20 days dry spells at Kamboinse). Daylength-sensitive cultivars which flower in late September and mid-October can be subjected to severe drought during flowering and pod formation and experience severe yield losses in both northern Guinea and Sudan savannas. They thus constitute a high risk to farmers.

In the Sahel, only daylength-insensitive cowpeas, sown in early to mid-July, which must complete their growth cycle by mid to late-September can be used. Such cultivars must be drought resistant at all growth stages for them to give acceptable yields.

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30 Comportement Hydrique et Sensibilité à l'Erosion de quelques sols du Nord-Cameroun

par BOUKA L. SEINY

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Resume La zone semi-aride du Cameroun s'étend du 9è au 13è Lat. N. Les pluies de repartition irrégulière s'étalent de Mai-Juin à Septembre-Octobre et il y tombe environ 700 mm/an (moyenne de 15 ans) –

Dans ce cadre où le principal facteur limitant à la production agricole est l'eau, il nous est paru nécessaire de mener des investigations sur l'efficacité des pluies dans la recharge en eau du sol tout en tenant compte des conséquences érosives des précipitations.

Par le moyen des averses simulées (Infiltromètre à aspersion) certains sites représentatifs des sols de la région ont pu être testés – Il ressort des résultats que les caractéristiques physico-hydriques des sols dépendent des facteurs tels que milieu, état de surface, travail du sol . . . Cependant, pour une meilleure appréciation du régime hydrique des sols, il convient de tenir compte de la notion d'aridité édaphique par des études en bassin versant.

Problématique

Le Nord Cameroun est constitué par des montagnes culminant souvent au-delà de 1000 m; des plateaux d'altitude situés entre 800 et 1000 m, et au pied des montagnes par des ensembles de glacis, de plaines, de piedmonts et de vallées alluviales.

La pluviosité moyenne de la région se situe entre les isohyètes inter-annuelles de 500 et 1000 mm. Les habitants de vette zone vivent principalement de l'agriculture et de l'élevage.

Depuis quelques décennies, l'augmentation de la population (taux de croissance 1,5%) et l'abandon progressif des terroirs montagnards ont conduit à des pressions accrues sur les plaines et les plateaux de façon souvent anarchique, et à la dégradation des ressources naturelles:

– Les savanes arborées en bon état disparaissent rapidement alors que le Nord Cameroun a un besoin crucial et soutenu en bois

– Les terres défrichées, dégradées (diminution de la fertilité, destruction, battance, etc. . .) puis abandonnées sont soumises même en plaine à une érosion d'autant plus intense, que ces sols ont été fragilisés et sont dépourvus de protection végétale; ceci est aggravé par le caractère très violent des précipitations.

– L'efficacité des précipitations dans la recharge des réserves en eau du sol diminue.

C'est dans ce contexte de déséquilibre biologique que nous avons entrepris de mener des études sur 2 contraintes majeures du développement agro-sylvo-pastoral à savoir:

1°) L'insuffisance et la mauvaise gestion des ressources en eaux, leur maîtrise

2°) La dégradation des ressources en sols suite à une utilisation souvent inappropriée –

I – Le Cadre Naturel

Climat

– Caractéristiques climatiques principales:

Le climat qui prévaut dans la zone d'étude est de type Soudano-Sahélien dont le paroxysme des pluies a lieu en Juillet-Août. L'évaporation peut dépasser 11 mm/j en Avril. Par ailleurs la saison sèche est amplifée par l'harmattan, vent desséchant faisant descendre l'humidité relative moyenne de l'air à moins de 30% en décembre, janvier, février et mars. Cette zone appartient à l'aire semi-aride

. Caractéristiques de la pluviosité

– Variabilité inter-annuelle

La moyenne des 41 dernières années de la Station de Maroua-Agro se chiffre à 784 mm. Les écarts inter-annuels sont importants. Le coéfficient de variabilité est de l'ordre de 1,8 (594 et 600 mm en 1967 et 1983; plus de 1000 mm en 1952, 62 et 80). En fait cette situation est encore plus défavorable, si nous analysons les probabilités au cours de l'année des dates de fin et de début des saisons des pluies.

– Les intensités des averses

- Les intensités moyennes supérieures à 100 mm sont exceptionnelles
- Les averses d'intensités I ≥ 50 mm/h contribuent pour environ 20% des hauteurs annuelles
- Les averses I ≥ 30 mm/h représentent près de 50%

– L'indice d'agressivité climatique

La valeur moyenne annuelle est de 303 avec des valeurs extrêmes de 473 et 155 – Les pluies inférieures à 10 mm n'ont pas été prises en compte – Les pluies à R ≥ 20 contribuent en moyenne à près de 40%.

Les sols

Les sols se sont développés sur 2 types de matériaux géologiques

– Les matériaux acides quartzeux ou quartzofelds pathiques (granite, gneiss, dunes sableuses, alluvions ou colluvions sableuses)

– Les matériaux basiques mais aussi riches en fer (micaschistes, certains gneiss, etc. ..)

Les sols qu'on y rencontre sont:

- Les sols areniques ou à dominance lithique
- Les sols peu évolués d'apport
- Les sols ferrugineux pour les matériaux acides et
- Les sols ferralitiques (ou rouges tropicaux)
- Les vertisols lithomorphes
- Les vertisols hydromorphes dans les bas-fonds pour les matériaux basiques

II – Matériel et Méthode

Nos études sur le régime hydrique et la sensibilité des sols à l'érosion se mènent sur des sites représentatifs des grandes unités pédologiques de la région.

Ce sont:

- Les sols hardés (terme local qui désigne les sols stériles)
- Les Vertisols dégradés
- Les Vertisols modaux
- Sol intergrades Vertisols-ferralitiques
- Sols ferrugineux

Chaque site est un dispositif composé de 3 parcelles unitaires (1m2) et de 4 tubes de soude à neutrons. Par ailleurs, un mini BV de 3000 m2 a été également amenagé. Un exutoire de 17.3 m3 de 3 pluviomètres.

- Nos investigations se font suivant 2 méthodes:
  - En conditions naturelles (pluies de Mai à Septembre)
  - En conditions artificielles (pendant la Saison sèche à l'aide d'un infiltromètre à aspersion)
- Elles se font à 3 échelles:
  - La mini-parcelle (1m2)
  - Le mini BV (2000 m2)
  - Le BV (22 km2)

Les Mesures en conditions naturelles concernent les 3 échelles précitées:

- La mini-parcelle
- Le mini-BV
- Le bassin versant

Les mesures en conditions artificielles (Simulateur)
Ce moyen de mesure ne concerne que les mini-parcelles (1m2)
L'approche méthodologique consiste sur cette surface unitaire représentative du milieu naturel retenu, à mesurer indirectement (par le ruissellement), la quantité d'eau infiltrée dans le sol (Pluie efficace dans la recharge des reserves en eau du sol) d'une averse ou d'une serie d'averses dont on contrôle toutes les caractéristiques (hauteur précipitée, durée, intensité, intervalle entre les deux averses, etc. . .)

Par ailleurs, sont suivies par la méthode du bilan d'eau des sols (humidimètre à neutrons ou méthode gravimètrique de la mesure d'humidité), la dynamique d'humectation des sols, ainsi que celle de leur déssèchement – Simultanément, au cours de ces simulations, des mesures sur la turbidité des eaux de ruissellement, sur le charriage sont effectuées à l'échelle de cette surface élementaire et nous permettent d'avoir une appréciation sur *l'érodibilité ou la sensibilité des terres à l'érosion hydrique* –

La conception de l'appareillage est pour l'essentiel, due à l'équipe du laboratoire expérimental des sols de l'ORSTOM en Côte d'Ivoire (ASSELINE, VALENTIN, CASENAVE).

Résultats et Discussions

Nous Nous limiterons dans le cadre de cet exposé aux mesures faites et conditions simulées. Les premiers résultats ont fait l'objet d'une publication de synthèse (PONTANIER et al 1984). Nous essayons d'en faire une synthèse en ce qui concerne les deux variables que nous testons, à savoir:

– L'efficacité de la pluie dans la recharge des reserves en eau du sol dèfinie par $Ke\% = \frac{Pe \text{ (Pluie infiltrée)}}{P \text{ (Précipitation)}}$

– La sensibilité des sols à l'érosion –

Tableau n° 1 Comportement global des parcelles à Mouda

		Hauteur totale des pluies simulées (mm).	Indice d'agressivité climatique pour l'ensemble des pluies simulées –R–	Coefficient d'efficacité des pluies dans la la recharge des reserves en eau %	Erosion totale d'une parcelle $1m^2$ (g)
Hardé	PM1	246	221	19	1338
	PM2*	111	104	63	383
Vertisol dégradé	PM3	111	104	25	616
	PM4	251	225	42	667
	PM5*	251	225	54	625
	PM6	111	104	34	637
Vertisol modal	PM7*	251	225	83	301
	PM8*	251	226	79	350
	PM9	251	226	70	211
Cuture coton	PM10*	251	226	74	1012
	PM11*	251	226	74	608
	PM12	251	226	55	627
Sol ferrugineux	PM13	251	226	62	227
	PM14*	251	226	62	700
	PM15	251	226	53	226

* Parcelle labourée au moins une fois.

Efficacité de la pluie

Il ressort de ce tableau, que différents facteurs influencent l'éfficacité des pluies dans la recharge en eau des reserves du sol

1 – L'unité pédalogique

En effet, suivant le type de milieu, Ke varie énormément; Ainsi, pour 245 mm précipités, avec R = 221, seulement 47 mm se sont infiltrés (19% sur PM1 "Hardé" et très battant), alors que pour une séquence sensiblement identique, ce sont 176 mm qui ont pu être absorbés par PM9 (Vertisol bien structuré et peu dégradé). Aussi, une corrélation Ke = f (R) peut être établie pour chaque type de milieu

2 – L'état de la surface du sol

L'appréciation visuelle du couvert de la pellicule de battance nous a permis de correler pour certaines pluies les coéfficients de ruissellement Kr (Kr = 100 – Pe) à une variable composite (C.B-V) % = couvert battance – couvert végétation, dont les deux termes sont antagonistes –

$$Kr = 0.85 \text{ (C.b-V)} - 3.04 \quad r = 0.975$$

3 – Le travail du sol

Bien que le labour (superficiel) améliore considérablement l'infiltration de l'eau, les résultats doivent être analysés par type de milieu (tableau n° 2).

Tableau n° 2 . Amélioration relative de Ke en fonction du travail du sol (R = 47)

	Hardé SM1	Vertisol dégradé SM2	Vertisol Modal SM3	Jachère Coton SM3	Sols ferrugineux SM5
Ke% moyen sans travail	21	41	69	54	44
Ke% moyen avec travail	65	82	92	75	71
Amélioration relative de Ke%	209	100	33	39	61

L'amélioration relative est surtout nette sur les milieux très dégradés (Hardé et Vertisol dégradé) – Il semble cependant que le labour n'a d'effet que pendant une seule pluie et que les phénomènes de battance réapparaissent très vite, surtout si le sol est soumis à des pluies agressives (40 <R<50)

Ces premier résultats sur l'éfficacité des pluies font apparaître les observations suivantes:

- Les pertes d'eau par ruissellement sont fonction du type de sol et peuvent atteindre 80% (cas des hardés)
- L'état de surface apparait primordial dans le comportement hydrique
- Le travail du sol améliore de façon considérable l'infiltration de l'eau mais ses effets sont de courte durée.

Sensibilité des sols à l'érosion

Toutes choses égales par ailleurs, notamment l'échelle d'étude, le tableau n° 1 montre que dans l'ensemble les milieux qui perdent le plus d'eau par ruissellement sont ceux qui s'érodent le plus, exception faite des parcelles travaillées – Pour ces parcelles labourées, on constate que le travail du sol tend à augmenter sa sensibilité, même s'il limite le ruissellement – Ainsi pour 251 mm précipités avec R = 226, la parcelle PM10 travaillée a été érodée de 1012 g (représentant 10.12 T/ha) alors que pour les mêmes averses, le témoin s'érodait de la moitié, bien que représentant un coéfficient de ruissellement supérieur de 34%.

D'une manière générale, pour 250 mm de précipités (R = 226) en 6 pluies, les extrêmes suivants ont été observés: 13.4 T/ha pour les hardés contre 2.1 T/ha pour les vertisols en bon état.

Conclusions – Perspectives

Ces premiers résultats de simulation de pluie en zone soudano-sahélienne appellent les remarques suivantes:

– Les milieux étudiés perdent plus ou moins d'eau par ruissellement. Si ces eaux "perdues" rejoignent le réseau hydrographique, une partie importante peut s'infiltrer progressivement en aval, d'où la nécessité de mener des études sur bassin versant – C'est ce que nous tentons d'entreprendre –

– L'Efficacité des pluies et la sensibilité à l'érosion des sols sont modulées par différents facteurs tels que: type de sol, travail du sol, état de la surface. Nous entreprenons de mettre en évidence l'influence de la dynamique de la végétation sur Ke et sur l'Erosion par l'intervention de la phyto-ecologie.

Néanmoins, dans le contexte d'aridité climatique, et avec le souci de maximiser la disponibilité en eau pour les végétaux, dans le cadre des principes de la conservation des sols, quelle attitude faut-il adopter quand on sait que les sols travaillés se rechargent mieux, mais s'érodent plus?

31 Chemical Characteristics and Agronomic Values of some Phosphate Rocks in West Africa

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Abstract Direct application of indigenous phosphate rocks can be an economical alternative to the use of imported, more expensive soluble phosphorus fertilizers for certain crops and soils in West Africa. Several countries in West Africa have workable or potentially workable deposits of phosphate rock. This paper summarizes the highlights to date of research done by the International Fertilizer Development Center (IFDC) on characterization and agronomic evaluation of some phosphate rocks in West Africa. The agronomic values of phosphate rocks were found to depend on the chemical reactivity of the rock, the properties of the soil to which they were applied, and the type of crop that was grown.

Introduction

Low fertility of the acid soils in tropical West Africa presents a serious problem that has inhibited the development of successful agriculture. Phosphorus (P) deficiency is a major constraint to production on these soils. However, use of P fertilizers is limited in the region due to the high cost of the imported fertilizers. Direct application of phosphate rock indigenous to the region may be an economical alternative to the use of more expensive soluble P fertilizers for certain crops and soils. Some West African countries have deposits which, if found suitable for direct application, would allow savings of much needed foreign exchange.

For several years, the International Fertilizer Development Center (IFDC) has conducted a comprehensive research program on the utilization of indigenous phosphate rocks for direct application to some soils and crops in West Africa. This paper summarizes the research highlights to date.

Characterization of Phosphate Rock

Location

Several countries in West Africa are known to have phosphate deposits (McClellan and Notholt, 1985). Figure 1 shows the locations of some important phosphate deposits in the region. The estimated total reserves and resources vary from location to location. At the present, Togo and

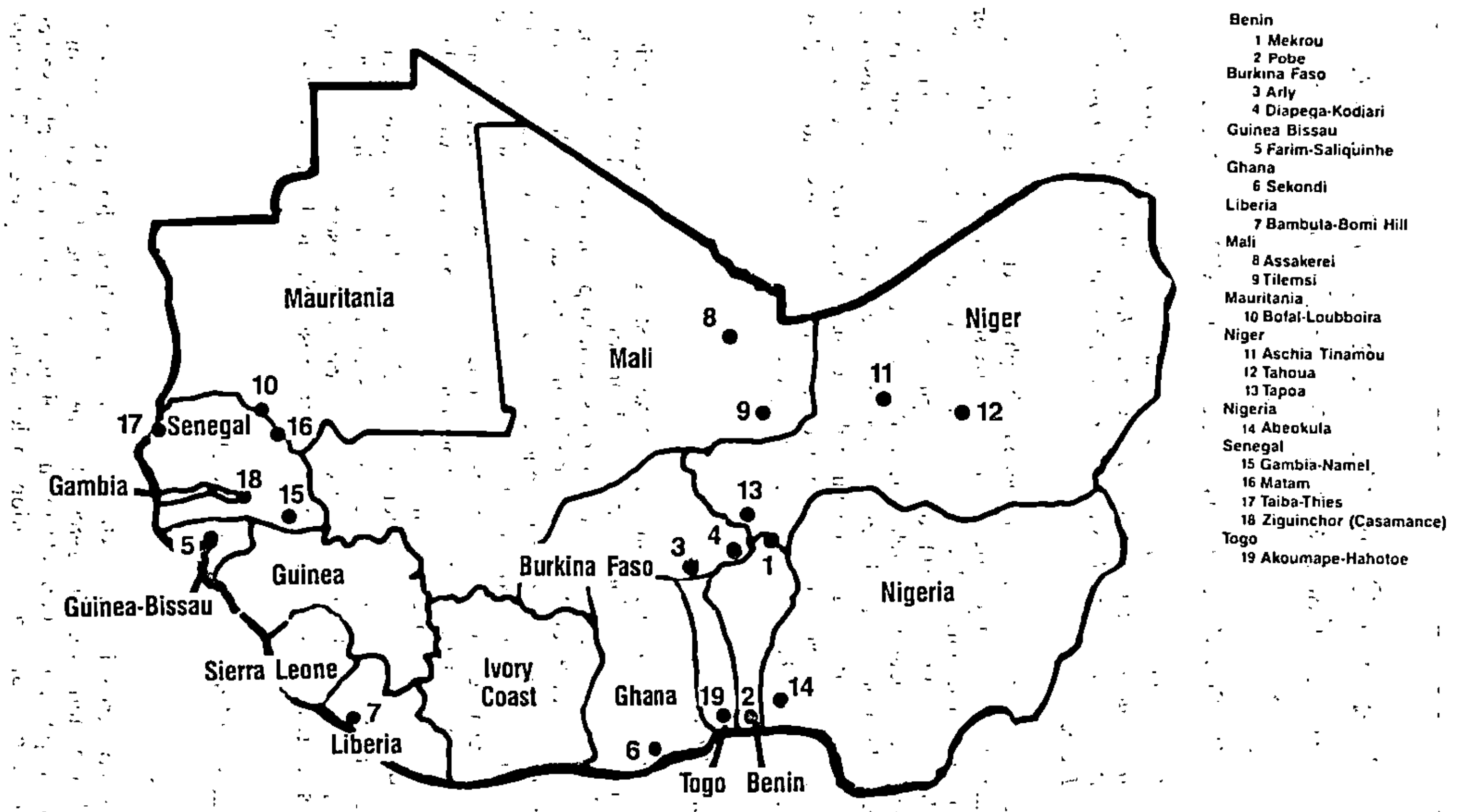

Figure 1 Phosphate Rock Deposits in West Africa. Adapted from McClellan and Notholt (1985).

Senegal are the only two major exporters of phosphate rock from the region. Potential does exist, however, for other countries to explore their phosphate deposits for either domestic and/or foreign consumption.

Mineralogical and Chemical Compositions

With the exception of the aluminum phosphate deposits in Pallo (near Thies) in Senegal, the principal phosphate mineral in most phosphate rocks in West Africa is apatite, but apatite varies widely in physical, chemical, and crystallographic properties. In general, the apatites are in the form of carbonate apatite with isomorphic substitution of carbonate for phosphate. Characterization of apatite in phosphate rock can now be made by chemical analysis, x-ray powder diffraction, petrographic microscopy, infrared spectroscopy, and electron microscopy.

The empirical formulas of the apatite in some representative phosphate rocks in West Africa as determined by the x-ray method are shown in Table 2. It can be seen that the length of unit-cell a-dimension of apatite decreases as carbonate substitution for phosphate in the apatite structure increases.

Table 1 Unit-Cell a-Dimension and the Empirical Formulas of the Apatite in Some Representative Phosphate Rocks in West Africa

Rock Sample	Length of a-Axis, Å	Empirical Formula
Matam, Senegal	9.339	$Ca_{9.68}Na_{0.23}Mg_{0.09}(PO_4)_{5.10}(CO_3)_{0.90}F_{2.36}$
Hahotoe, Togo	9.351	$Ca_{9.79}Na_{0.15}Mg_{0.06}(PO_4)_{5.39}(CO_3)_{0.61}F_{2.24}$
Kodjari, Burkina Faso	9.360	$Ca_{9.87}Na_{0.09}Mg_{0.04}(PO_4)_{5.62}(CO_3)_{0.38}F_{2.15}$

Table 2 Total and Citrate-Soluble P_2O_5 of Some Phosphate Rock Samples from West Africa

Rock Sample		Total P_2O_5	NAC-Soluble P_2O_5[a]
Country	Location	(%)	
Senegal	Matam	29.8	4.5
Mali	Tilemsi	28.6	4.2
Niger	Parc W	28.5	2.6
	Tahoua	(vary)	2.5-5.0
Burkina Faso	Kodjari	25.3	2.3
Togo	Hahotoe	35.9	3.0

a. Neutral ammonium citrate method.

Chemical Reactivity

Chemical reactivity of phosphate rock is one of the key factors in determining whether a phosphate rock is suitable for direct application. The most commonly used methods in the world to measure the chemical reactivity of phosphate rock are: neutral ammonium citrate, 2% citric acid, and 2% formic acid.

Table 2 shows the solubility of some representative phosphate rocks in West Africa as extracted by the neutral ammonium citrate method. Solubility increases as carbonate substitution for phosphate in the apatite structure increases in accordance with the theoretical considerations (Chien, 1977). (Figure 2) Thus, the degree of isomorphic substitution is a key factor in determining the chemical reactivity of phosphate rock containing carbonate apatite. Diamond (1979) proposed a classification of phosphate rock for direct application based on citrate solubility as $\geq$ 5.4%, high; 3.2%/4.5%, medium and $\leq$ 2.7%, low. Based on this classification, Matam (Senegal), Tilemsi (Mali), and Tahoua (Niger) rocks are medium in reactivity, whereas other rocks in West Africa are low in reactivity (Table 2).

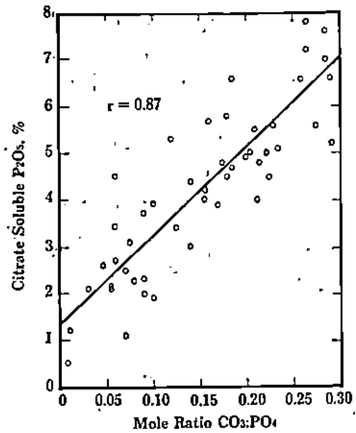

Figure 2 Relationship between Citrate Solubility and Mole Ratio of CO_3:PO_4 of Apatite in Phosphate Rocks. (Lehr and McClellan, 1972).

Agronomic Value of Phosphate Rock

Greenhouse Evaluation at IFDC Headquarters

Short-term greenhouse trials have been used to evaluate the agronomic potential of phosphate rock as influenced by chemical reactivity of phosphate rock. Figure 3 shows the dry matter yield of maize obtained with various sources of phosphate rock from western and northern Africa against TSP on an Ultisol. Under these greenhouse conditions, all the phosphate rocks were inferior to TSP in increasing plant yield. Phosphate rocks from northern Africa were more effective than those from western Africa, and there was a significant relationship between plant yield and rock's citrate solubility (Figure 4).

In another trial with cowpeas, the agronomic value of three African phosphate rocks were found to follow the order of Gafsa > Tilemsi > Kodjari (Figure 5), which is in the same order of their citrate solubilities and soil solution P concentrations (Figure 6). It is noteworthy that the effectiveness of Tilemsi rock in relation to the effectiveness of Gafsa rock was higher with the cowpea crop than with maize. Khasawneh and Sample (1979) suggested that cowpeas may require a concentration of soil solution P for maximum growth potential that is only two-thirds of that required for maize. If this is true, it suggests that the relative agronomic effectiveness of less reactive phosphate rocks may be higher for crops with lower P demands such as legume crops than with maize. More research work is needed to test this hypothesis.

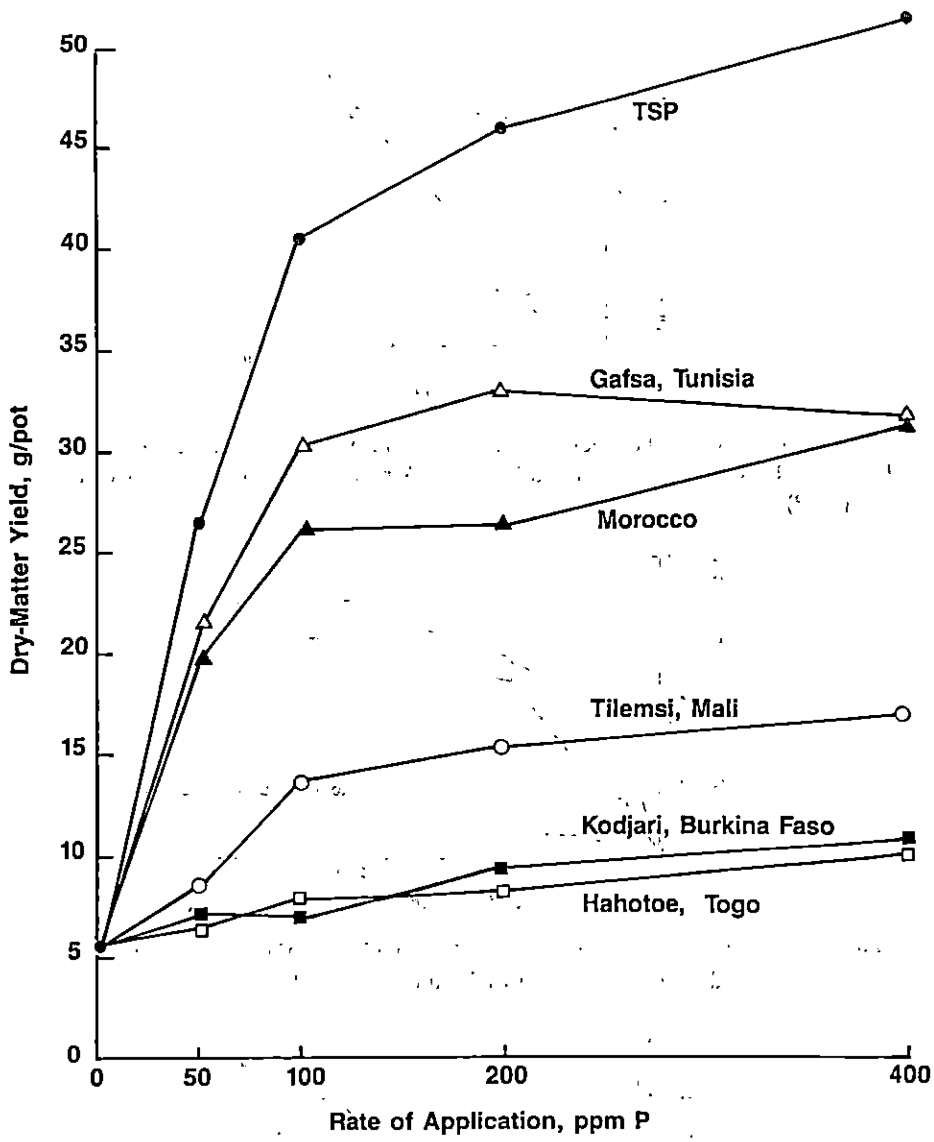

Figure 3 Dry-Matter Yields of Maize in Greenhouse from Various Finely Ground Phosphate Rocks and TSP after 6-Week Growth Period (IFDC unpublished data).

Field Evaluation in West Africa

The agronomic effectiveness of phosphate rock under field conditions is not only dependent on the chemical and mineralogical properties of the rock but also on the properties of the soil and the crops to be grown. For example, the relative agronomic effectiveness of Togo rock with respect to SSP in increasing maize grain yield was only 11% in a savanna Alfisol (Zaria) in Nigeria (Figure 7). whereas it increased to 46% in a forest Ultisol (Njala) in Sierra Leone (Figure 8). The lower pH of the Ultisol (pH 4.0) than that of the Alfisol (pH 5.8) probably favored greater dissolution of Togo rock in the soil.

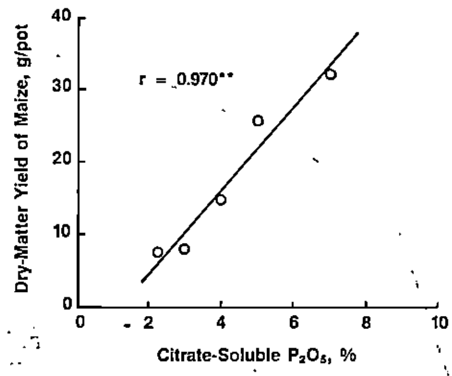

Figure 4 Relationship between Dry-Matter Yield of Maize Obtained with Various Phosphate Rocks from Western and Northern Africa and Citrate Solubility (P rate = 200 ppm P).

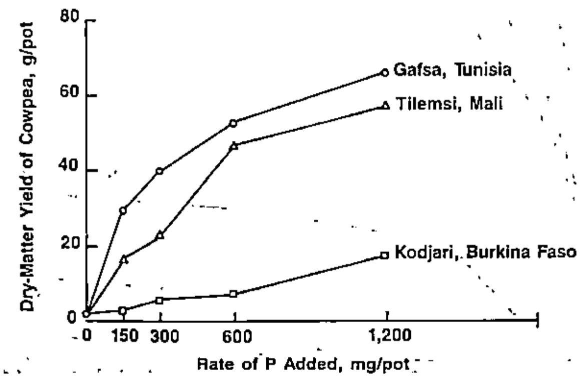

Figure 5 Dry-Matter Yield of Cowpeas Obtained with Various Phosphate Rocks after 6 Weeks. Adapted from Khasawneh and Sample (1979).

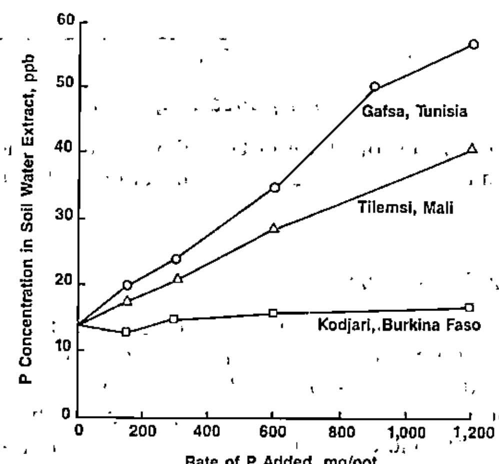

Figure 6 Soil Solution P Concentrations in the Soil Treated with Various Phosphate Rocks after Sequential Harvesting of Cowpeas (Means of 3, 4, 5, and 6 weeks). Adapted from Ihasawneh and Sample (1979).

At Sapu on an Oxisol in the dry region of Gambia, the agronomic effectiveness of Tilemsi (Mali) rock was found to be 74% and 92% as compared with SSP for maize (Figure 9) and groundnuts (Figure 10), respectively. This confirms the general observation of other researchers that Tilemsi rock is reactive enough to be used for direct application. It is also interesting to note that groundnuts appear to be more effective than maize in utilizing the rock, an observation that tends to support the previous suggestion that legume crops may be more effective than nonlegume crops in utilizing phosphate rock.

In Niger two indigenous phosphate rocks (Parc W and Tahoua) were evaluated on an Alfisol (Gobery) for millet production. While the less reactive Parc W phosphate rock was only 48% as efficient as SSP, the effectiveness of the more reactive Tahoua rock was as high as 76% (Figure 11). In Burkina Faso an indigenous rock (Kodjari) was found to be 62% as efficient as SSP in increasing sorghum grain yield (Figure 12).

It appears that although those less reactive phosphate rocks such as Parc W and Kodjari are much less effective than soluble P fertilizers such as SSP, a significant increase in crop yield can be obtained with these rocks compared with the unfertilized (no P added) treatments. For example, an application of 30 kg of P_2O_5/ha of Parc W rock almost doubled the millet grain yield compared with the plot that received no P fertilizer (Figure 11).

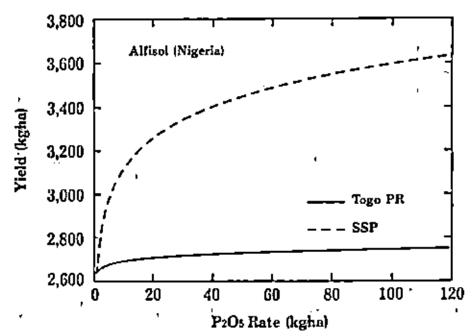

Figure 7 Maize Grain Yield Obtained with Togo Phosphate Rock (PR) and Single Superphosphate (SSP) in a Savanna Alfisol in Nigeria. Adapted from Bationo et al (1985).

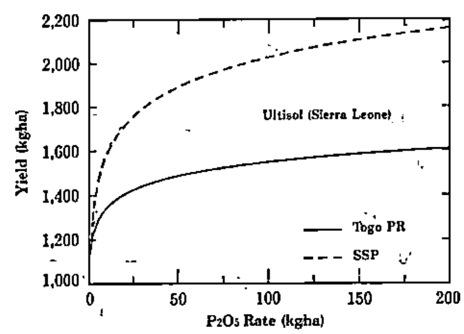

Figure 8 Maize Grain Yield Obtained with Togo Phosphate Rock (PR) and Single Superphosphate (SSP) in a Forest Ultisol in Sierra Leone. Adapted from Bationo et al (1985).

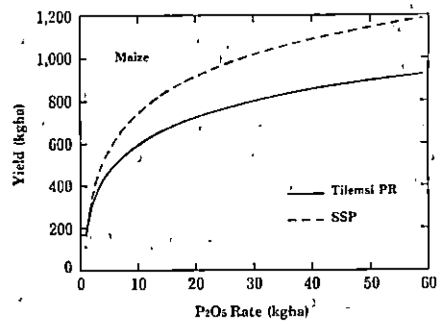

Figure 9 Maize Grain Yield Obtained with Tilemsi Phosphate Rock (PR) and Single Superphosphate (SSP) in an Oxisol in Gambia. Adapted from Bationo et al (1985).

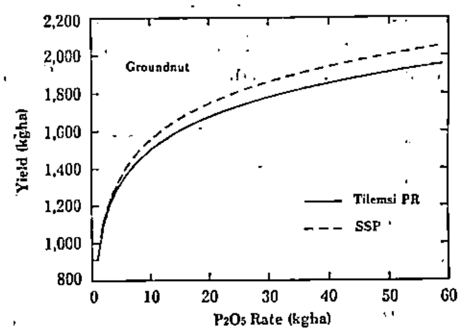

Figure 10 Yield of Groundnuts obtained with Tilemsi Phosphate Rock (PR) and Single Superphosphate (SSP) in an Oxisol in Gambia. Adapted from Bationo et al (1985).

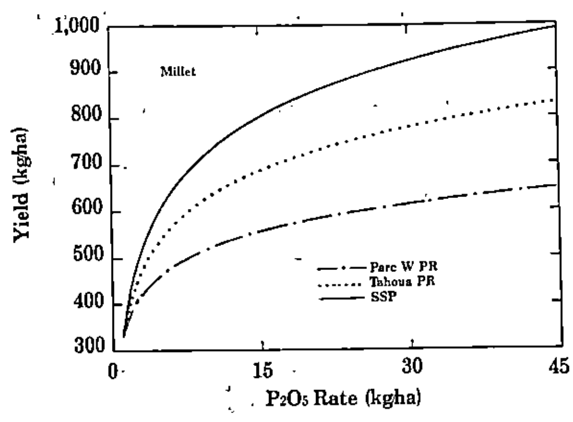

Figure 11 Millet Grain Yield Obtained with Two Phosphate Rocks (PR) and Single Superphosphate (SSP) at Gobery in Niger. Adapted from Bationo et al (1985).

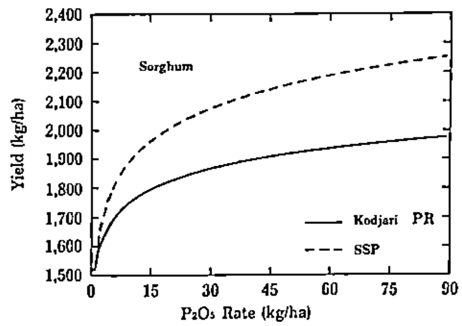

Figure 12 Sorghum Grain Yield Obtained with Kodjari Phosphate Rock (PR) and Single Superphosphate (SSP) in Burkina Faso. Adapted from Bationo et al (1985).

Thus even the less reactive phosphate rocks in West Africa could be economically considered for direct application for certain soils and crops.

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32 Soil Fertility Constraints in Improving Cereal Yields in Soils of the Arid and Semi-Arid Areas of Kenya

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Abstract Arid and semi-arid areas constitute about 83% of Kenya's total surface area of some 583,000 square kilometres. They are characterised by relatively low average annual rainfall and high evaporation. The ratio rainfall (r) over potential evaporation (Eo) is less than 40. The seasonal rainfall in most of the area is not only unreliable but also has a poor distribution.

Eighteen major soil types are found in the arid and semi-arid areas of Kenya. They vary greatly in both physical and chemical characteristics. They range from deeply weathered well drained reddish soils, well drained dark coloured soils to imperfectly or poorly drained dark coloured soils. A substantial portion of these sites are saline or sodic or both. The chemical fertility of these soils are widely variable. The deeply weathered soils are in general chemically poor and have little or no reserve of plant nutrients. The other soils, although they may be adequately supplied with plant nutrients, they may have other unfavourable soil conditions which may affect the availability of the nutrients to plants. Coupled with the problem of low soil moisture availability most of the soils have in general low organic matter content and hence are low in nitrogen. Phosphorus and Nitrogen are the major nutrients limiting cereal yields in these soils.

This paper gives a brief outline of the major soils of the arid and semi-arid areas of Kenya and discusses their soil fertility constraints with special reference to improvement of cereal production.

Introduction

On the basis of the ratio of average annual rainfall (r) and average annual potential evaporation (Eo) Kenya can be divided into seven classes of moisture availablity (Braun, 1980 and 1982). Three of these classes (agro-climatic zones V, VI and VII) whose upper boundary of r/Eo ratio are 40, 25 and 15 per cent respectively constitute the semi-arid, arid and very arid areas of Kenya. The three zones together cover 83 percent of the country and the arid zone (VII) above covers nearly half of Kenya (Braun and Mungai, 1983). Table 1 gives a breakdown of the water availability zones in Kenya with an indication of their agricultural potential. The semi-arid zones are of low to marginal agricultural potential under rainfed conditions due to unreliable and poorly distributed seasonal rainfall. However, under good soil and water management practices these areas can be used for producing cereal crops such as Sorghum, Millets and early maturing Maize varieties.

Important Soil Types in these Areas

Figure 1 gives the distribution of the major soils found in the arid and semi-arid areas of Kenya. The soils are classified according to the concepts of the FAO/UNESCO Soil Map of the World (FAO, 1974). The soils are found

Zone	r/Eo	Classification	Average annual rainfall (mm)	Average annual potential evaporation (mm)	Average number of growing days	Agricultural potential	Approximate area in thousand of ha.	Percent of nations land area
I	>80	very humid	1100-2700	2000	365	very high	2440	4.4
II	65-80	humid	1000-1600	1300-2100	290-365	high	1220	2.2
III	50-65	semi-humid	800-1400	1450-2200	235-290	high to medium	2140	3.9
IV	40-50	sub-humid to semi-arid	600-1100	1550-2200	180-235	medium	3670	6.7
V	25-40	semi-arid	450-900	1650-2300	110-180	marginal	7640	13.9
VI	15-25	arid	300-550	1900-2400	75-110	low	11600	21.1
VII	<15	very arid	150-350	2100-2500	<75	very low	26290	47.8

r = average annual rainfall in mm

Eo = average annual potential evaporation in mm

Source: Sombroek et al, 1982

Table 1 Water availability zones in Kenya with an indication of their agricultural potential

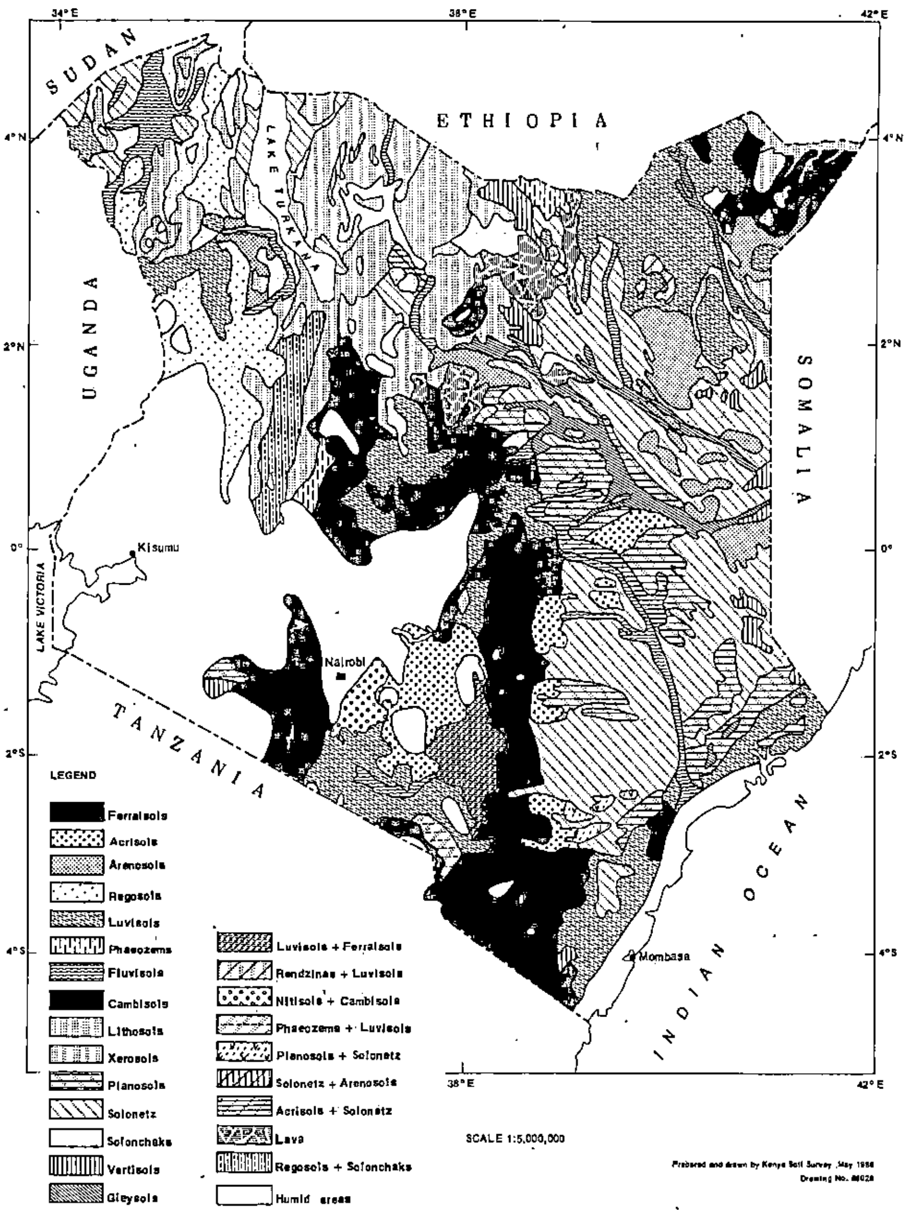

Figure 1 Distribution of soils of the arid and semi-arid areas of Kenya.

under different land forms and are developed from a wide range of parent materials. In this paper only a brief description of the soils is given with emphasis on their soil fertility.

Ferralsols are strongly weathered and leached and therefore, are chemically poor. Their natural fertility is restricted to the A-horizon and related to the organic matter content. Addition of fertilizer or manure is necessary for optimum crop production. These soils have excellent capacity to hold moisture, since they are deep and porous and have generally high clay content.

Acrisols are strongly weathered soils of low chemical fertility. The subsoil is often little porous and therefore restricts rooting and is relatively low in water storage capacity.

Arenosols are well drained soils with sandy coarse textures. They commonly occur on quartz-rich parent materials. The topsoil is low in organic matter. The soils have very low cation exchange capacity per unit volume and hence are of low chemical fertility. Heavy application of fertilizer is necessary for agricultural production.

Regosols are stony and rocky soils of widely variable chemical fertility. Their fertility depends on the parent material. They have a low moisture storage capacity.

Luvisols are common in semi-arid areas and they resemble the Acrisols. They have a moderate natural fertility. However, they have a tendency to form a strong seal on the surface which leads to low infiltration rates. This results into a lot of run off and easily leads to erosion of the fertile topsoil.

Phaeozems are soils with dark coloured topsoil which is high in organic matter and is non-acid. They are usually very fertile because they contain large quantities of organic matter, abundant mineral nutrients and have an excellent physical structure.

Fluvisols are young soils developed on alluvium of recent origin. Their fertility is related to the nutrient content of soils and rocks in the watershed from which the alluvium came. For example, alluvial soils from erosion products of sandstones, granitoid gneisses and shales are relatively low in fertility but those from limestone, basalts and rocks rich in ferromagnesian minerals are relatively fertile. Most of the Fluvisols along large rivers are of mixed origin and are therefore moderately well supplied with plant nutrients.

Cambisols are young little weathered soils of high natural fertility.

Lithosols are shallow, stony and rocky soils. Their fertility depends on the parent material.

Xerosols are soils developed under dry climatic conditions. They have low organic matter. Drainage conditions vary. Most are calcareous, some are saline and/or sodic.

Planosols (Vlei soils) are imperfectly drained. They are often waterlogged and have very slow vertical and horizontal drainage. Their soil fertility status ranges from low to moderate.

Solonetz are alkaline soils that contain little soluble salts but much exchangeable sodium harmful to crops. They have a pH between 8.5 and 10.

Solonchaks are saline soils which contain so much soluble salts that is harmful for the growth of agricultural crops, mainly because of the high osmotic pressure of the soil solution which reduces the availability of water to plants. Solonchaks contain many salt crystals, are commonly light coloured and are poor in organic matter.

Vertisols are dark, cracking soils popularly known as black cotton soils. They are usually poorly drained and are fine in texture – more than 35 per cent clay. Chemical fertility of vertisols is usually high except for nitrogen and phosphorus.

Gleysols are poorly drained mineral soils which are periodically waterlogged. Artificial drainage is the most important management problem. Their fertility is widely variable. Some are very acid whereas others have topsoil with high organic matter.

Other soils encountered in the semi-arid areas are Nitisols, Randzinas and Andosols. Nitisols are soils deeper than 150 cm, usually red, porous and friable. They have favourable moisture storage capacity and aeration. Their chemical fertility is variable. For optimal crop production they require fertilizer or manure. Randzinas are usually shallow soils developed on limestone. They have high organic matter content and are chemically rich. Andosols are soils formed from recent volcanic material. They are very porous, have a low bulk density, high organic matter and a high water storage capacity. In general they are fertile.

Soil Fertility Status

Soil fertlity can be broadly defined as the natural ability of the soil to provide plants with nutrients, water and oxygen. Chemical soil fertility on the other hand is restricted to the capacity of a soil to provide plants with nutrients. It depends on the degree of chemical weathering and leaching, is related to the organic matter content and the rate of its decomposition. Chemical soil fertility can be improved by application of chemical fertilizers or organic manures.

The chemical soil fertility of the soils of the arid and semi-arid areas of Kenya is widely variable. Table 2 gives some soil chemical characteristics of topsoils of some soils found in these areas. The bulk of the soils have low contents of organic matter (%C less than 1.0) and nitrogen (%N less than 0.15). The phosphorus content in most of the soils range from 3 to 20 ppm. According to the method of extraction (Mehlich *et al*, 1962) these values are considered as low and plants grown on such soils may show a P-deficiency. Ferralsols, Arenosols, and humic Cambisols are poorly supplied with calcium and magnesium. Some Planosols, Cambisols, and Arenosols are low in potassium. The rest of the soils are adequately supplied with potassium. However, it should be noted that under continuous cropping of cereals potassium deficiencies may be observed particularly in those soils which have a low K potential (Muchena, 1975). Most of the Ferralsols, Acrisols and Arenosols are strongly acid and require liming for optimum crop production.

Luvisols which are widely represented in the semi-arid areas of Kenya have a fairly high base saturation but have a clay fraction with correspondingly low exchange capacity. They have low levels of organic matter which makes them very suscpetible to degradation. Although these soils have relatively higher inherent fertility than the Ferralsols and Acrisols and can support a wide range of crops, they may show dramatic yield declines if allowed to erode.

Solonchaks and Solonetz may be adequately supplied with most of the plant nutrients but their high salt content and exchangeable sodium percentage respectively makes them unsuitable for growing cereals.

Most of the red soils (rhodic Ferralsols, chromic Luvisols, ferric Luvisols, chromic Cambisols and ferric Acrisols) found in the semi-arid areas have high amounts of iron oxides and have a tendency to fix phosphorus.

Soil Type classified according to FAO,1974	No of profiles	Available nutrients (Mehlich et al 1962)					%C	%N	CEC clay NaOAC pH 8.2 (me/100g)	Base Saturation	pH(1:2.5 v/v)		EC mmho/cm
		Na (me%)	K (me%)	Ca (me%)	Mg (me%)	P (ppm)					H_2O	KCl	
rhodic Ferralsols	1.3	0.06* (0.01-0.10)**	0.64 (0.28-0.98)	2.24 (0.6-5.4)	2.09 (0.8-4.0)	7.4 (3 - 14)	1.08 (0.52-1.58)	0.10 (0.07-0.14)	14.96 (12.8-17.0)	53 (18-90)	5.4 (4.5-6.6)	4.7 (3.8-5.4)	0.06 (0.01-0.19
orthic Ferralsols	2	0.08 (0.06-0.10)	0.45 (0.04-0.50)	1.50 (1.2-1.8)	1.65 (1.6-1.7)	7.5 (4-11)	0.70 (0.69-0.71)	0.08	16.0	52 (46-57)	6.1 (6.1-6.2)	5.4 (4.9-5.9)	0.07 (0.04-0.10)
plinthic Acrisols	1	nd	0.5	2.8	2.0	18	1.0	0.07	19.0	62	5.8	5.3	0.18
ferralic Arenosols	2	0.04	0.16 (0.14-0.17)	1.3 (1.0-1.6)	0.5 (0.4-0.6)	14.5 (9-20)	0.32 (0.29-0.35)	0.04 (0.03-0.05)	55.5 (41-70)	67. (57-76)	5.7 (50-64)*	5.1 (4.7-5.4)	0.02 (0.02-0.03)
eutric Regosols	1	0.10	0.32	8.8	4.2	151	1.37	0.11	32.5	94	6.2	5.1	0.08
chromic Luvisols	9	0.06 (0.01-0.10)	0.52 (0.34-0.72)	3.7 (1.8-6.8)	1.9 (1.1-2.8)	19.1 (6-45)	0.86 (0.40-1.54)	0.09 (0.07-0.12)	33.8 (23-42)	80 (51-100+)	6.5 5.4-7.4	5.1 (3.7-6.5)	0.17 (0.04-0.94)
orthic Luvisols	11	0.09 (0.01-0.34)	0.67 (0.16-1.20)	3.8 (1.6-10.8	2.0 (1.0-4.4)	42 (6-200	0.77 (0.36-1.13)	0.08 (0.04-0.15)	34.7 (18-73)	86 (53-100+)	6.9 6.0-8.2	5.2 (4.1-6.6)	0.09 (0.02-0.15)
ferric Luvisols	1	0.04	0.74	4.8	2.9	17	1.32	0.10	23.6	93.	6.5	4.6	0.07
haplic Phaeozems	2	0.03 (0.02-0.04)	0.42 (0.32-0.51)	2.6 (1.2-4.0)	1.15 (0.7-1.6)	13 (4-22)	0.98 (0.89-1.06)	0.10. (0.09-0.11)	32.5 (27-38)	77 (61-92)	6.4 6.1-6.7	5.0 (4.9-5.0)	0.04
luvic phaeozems	1	0.05	0.54	1.4	1.0	11	0.83	0.07	28.2	72	7.7	6.3	0.14
eutric Fluvisols	3	0.82 (0.11-1.54)	0.46 (0.29-0.66)	13.6 (2.0-24.0	3.4 (1.6-5.7)	159 (4-240)	0.3 (0.2-0.38)	0.03 (0.03-0.04)	57.3 (16-98)	68 (54-83)	6.8 (4.8-7.8)	5.5 (4.2-6.6)	0.18
chromic Cambisols	1	0.07	0.46	3.0	1.8	12	0.43	0.09	22	89.	5.3	nd	0.25
humic Cambisols	1	0.10	0.17	0.2	0.4	16	3.49	0.30	57.5	15.	4.8	3.9	nd
calcic Cambisols	1	0.07	0.60	8.8	4.4	114	1.29	0.13	50.4	100+	6.9	5.7	0.16
haplic Xerosols	9	0.60 (0.17-1.45)	0.91 (0.21-1.97)	22.2 (9.0-30.4	6.9 (5.0-9.0)	17 (6-44)	0.58 (0.42-0.73)	nd	75.2 (56-89)	100+	8.3 (7.8-8.5)	6.8 (6.1-7.2)	0.22 (0.15-0.35)
luvic Xerosols	5	0.72 (0.35-1.08)	0.98 (0.37-1.77)	19.6 (8.2-28.4	7.0 (5.7-8.0)	12 (4-26)	0.59 (0.48-0.8	nd	73.1 (62-118)	89 (61-100+	8.0 (6.7-8.7)	6.5 (5.4-7.5)	0.34 (0.06-0.55)
humic Planosols	1	0.18	0.10	2.2	1.9	4	1.12	0.12	21.0	48	6.5	5.0	0.06
orthic Solonetz	4	2.8 (1.18-4-56)	0.47 (0.34-0.75)	17.8 (4.3-23.9	7.2 (6.2-7.6)	13 (8-16)	0.71 (0.56-0.89)	nd	75.9 (61-94)	100+	7.9 (7.4-8.2)	nd	1.1 (0.4-3.4)
gleyic Solanchak	1	11.4	1.7	32	7.6	26	0.4	0.03	45	100+	8.7	7.2	1.3
pellic Vertisols	2	0.33 (0.22-0.44)	0.40 (0.33-0.46)	22.6 (1.2-34.0	3.7 (3.1-4.2)	38.5 (28-49	1.27 (1.07-1.46)	0.10 (0.09-0.11)	101.5 81-121	100+	7.7 (7.1-8.3)	6.3 (5.7-6.9)	0.15 (0.05-0.24

* average figures nd - not determined

** range

Sources: Sketchley et al, 1978; Touber, 1983; Muchena and Njoroge; in prep; Muchena and van der Pouw, 1981

Table 2 Soil chemical characteristics of topsoils (0-30 cm) of some soils of the semi-arid areas of Kenya

The soils in the semi-arid areas of Kenya are also reported to be deficient in copper, zinc and sulphur (Ikombo, 1984). However, very little work has been carried out on soil fertility status of most of the soil types found in the semi-arid areas of Kenya. The only soils that have been extensively studied are chromic Luvisols found at Katumani and Ithokwe. Nadar and Faught (1984) conducted field experiments in a chromic Luvisol at Katumani Dryland Farming Research Station to test yield responses of 120-day maize Katumani composite B to the application of five levels each of phosphate and nitrogen fertilizer. They found that maize yield levels varied significantly from one season to another. The overall yield averaged 653 kg/ha for the seasons with the lowest rainfall and more than 3000 kg/ha for the seasons with adequate rainfall. This indicated that rainfall conditions were the major factors influencing maize yield response to fertilizer applications. They also found that although yield responses to phosphate fertilizer levels were not significantly different from the control, there was a constant and positive yield response to phosphate application especially at 8.75 kg/ha. This may be an indication that for chromic Luvisols under Katumani conditions 8.75 kg P/ha was an essential nutrient requirement for optimum maize production. Okalebo (19895) conducted field trials to study bulrush millet responses to nitrogen and phosphorus fertilizers on a chromic Luvisol at Ithokwe and found that 60 kg N/ha plus 40 kg P/ha treatment in ridges gave the highest grain yield with an increase of 1981 kg/ha (125% grain yield increase). Applied phosphorus gave significant grain yield increases in three successive seasons indicating direct and residual benefits of fertilizers. Ikombo (1984) conducting a long term manurial experiment at three sites (Katumani, Ithokwe and Kampi ya Mawe) to study the effect of farm yard manure and fertilizers on maize grain yields found out that the responses to both farm yard manure and fertilizers were very large in years of high rainfall. However, there were declines in yields during the dry seasons.

Conclusion

Cereal production in the arid and semi-arid areas is limited by inadequate rainfall and low soil fertility. Soil fertility influences the effectiveness of rainfall indirectly. Infertile soils can only support a poor crop stand with a poorly developed root system. Such a crop will not be able to extract water from deeper layers of the subsoil and may therefore develop a water stress even with a mild drought. Most of the soils in the arid and semi-arid areas of Kenya are low in phosphorus, nitrogen, organic matter content and possibly sulphur and micronutrients. Addition of these nutrients is necessary to ensure good crop growth and hence efficient utilization of available water.

In view of the fact that different soil types with variable physical characteristics are encountered in the semi-arid areas of Kenya, it is suggested that more soil fertility studies be carried out to cover the whole range of these soils.

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33 Soil Fertility and Crop Yields in Savanna Zones of Nigeria

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Abstract Organic carbon, total nitrogen, available P, effective CEC and exchangeable cations as well as clay and silt contents are low in soils of savanna zones of Nigeria. No obvious imbalance between exchangeable cations in the soils studied was observed. Mean ratio of Ca/Mg seems to be the most vulnerable cation whose availability may create a problem for intensive and continuous cultivation. Soil acidity was not found to be a serious problem for crop production on a regional basis. Generally the fertility status of Northern Guinea Savanna soils is higher as compared to Sudan Savanna and Southern Guinea Savanna soils. Organic carbon, total nitrogen and C/N ratio increased from Sudan Savanna to Southern Guinea Savanna soils following the rainfall pattern.

Higher yields of millets, sorghum and groundnuts can be obtained with proper use of fertilizers and by adopting improved packages of crop husbandry. The potential for crop production in the Northern Guinea Savanna is better than the Sudan and Southern Guinea Savanna zones. Soils in Sudan Savanna zones are very light in texture and the rainfall is low and therefore, needs proper management of soil moisture and fertility in order to sustain crop yields under continuous cultivation on a long term basis.

Introduction

The Savanna zones of Nigeria cover an area of about 700,000 square kilometers which is almost three-quarters of the country's area. Most of the farmers there practice subsistance farming. With the increasing pressure on land, continuous cultivation is slowly replacing traditional bush/fallow system of agriculture.

Most upland and well drained savanna soils are coarse textured, low in organic matter and poor in soil fertility (Balasubramanian et al. 1984). Although regional surveys of soil organic matter content and one or two plant nutrients are available (Jones, 1973, Anon, 1978) a comprehensive study of fertility status of these soils is lacking. A detailed evaluation of soil fertility is very important for efficient utilization of the soil resources and proper planning of land use. Information presented in this paper were gathered during the period 1975-1985 while conducting the field trials in four ecological zones of Nigerian Savanna namely Sahel Savanna, Sudan Savanna, Northern Guinea Savanna and Southern Guinea Savanna.

Various crops and varieties are being cultivated in these ecological zones in Nigeria (Figure 1). Some of the most important crops are sorghum, millet, groundnuts, maize, cotton, cowpea, yam, cassava, rice, wheat (under irrigations), sesamum and several vegetable crops.

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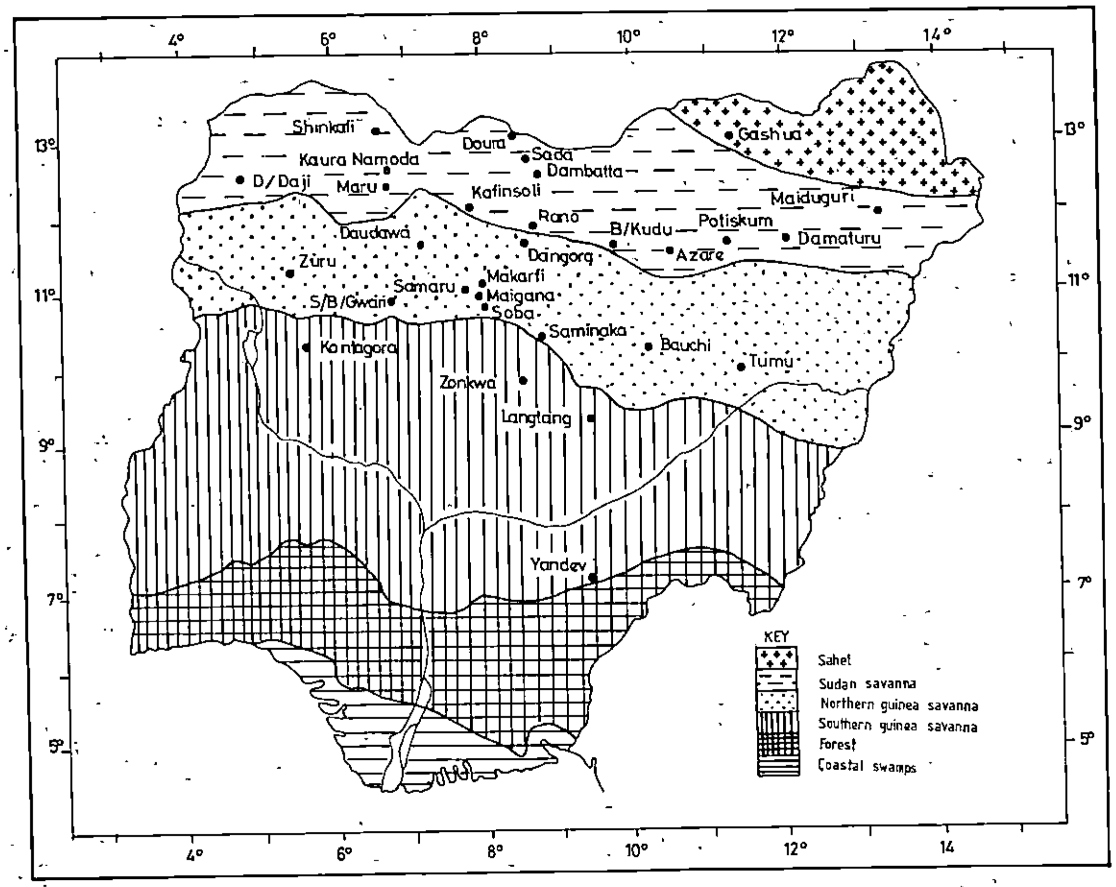

Figure 1 Map of Nigeria showing the ecological zones and some of the experimental sites

The most important crops in Sahel-Sudan Savanna zones are millet, sorghum, groundnut whereas sorghum, maize, groundnut and cotton are important in Northern Guinea Savanna. Long season sorghum, maize, yam and cassava are important crops in Southern Guinea savanna. Rice is planted in most of the low land areas in Northern and Southern Guinea savanna and to limited extent in Sudan Savanna zone. Wheat is being cultivated during the cold season (November to March) in Sudan zone under irrigation.

Materials and Method

Soil Sampling

Soil samples (0-20 cm) were collected from each of the experimental sites from 1975 to 1985. Each sample comprised a composite of 10-15 samples taken at random points from the selected area. Samples were air dried, ground to pass a 2 mm sieve and stored for later analysis. Sub-samples intended for organic carbon and total nitrogen analysis were further crushed to pass a 0.5 mm sieve.

Analytical Methods

Soil pH was measured in 0.01M $CaCl_2$ (at soil:solution ratio 1:2), organic carbon was determined by the Walkley-Black method and total nitrogen by Kieldahl distillation.

Exchangeable cations (Ca, Mg, and K) from the IN ammonium acetate leachate were determined by the use of an atomic absorption spectrophotometer (Parkin-Elmer Modal 306). Available-P was determined by the Bray-I method. Particle size analysis was done by the pipette method after dispersing the soil in calgon. All analyses were carried out as described by Black (1965).

Field Experiments

Field trials involving several crops were carried out in different ecological zones of Nigeria, mainly at Government Farm Centers or on cultivature's field following randomised complete block design. Recommended package of practices for each crop were followed in conducting the field trials.

Result and Discussion

Figure 1 indicates some of the locations in different ecological zones where most of the experiments were carried out and also the soil samples collected. In the present study only one site (Gashua) was located in the Sahel zone and the data was combined with the data from the Sudan Savanna zone, in the discussion of the results. A brief description of the soil sampling sites has been given in Table 1 together with annual rainfall data.

Soil pH

The mean pH value in 0.0 1m $CaCl_2$ solution was 5.4 and none of the

Table 1 Description of the sampling and experimental sites

Site	Rainfall (mm)	Soil Type	Land Resource Unit
Sahel-Sudan Savanna			
Gashua	510	Sandy loam	Yobe alluvium
Maiduguri	709	Sandy loam	Mafa alluvium
Damaturu	729	Loamy sand over chad sediment	Damaturu plains
Potiskum	800	Sandy drift over iron pan	Potiskum plains
Azare	787	Deep sand	Gadau dunefield
Kadawa	850	Sandy loam	Tiga plains
Kano	817	Sandy drift over iron pan	Kano plains
Dambatta	815	Sandy drift over iron pan or complex	Kano plains
Kafinsoli	805	Sandy loam drift over base complex	Dutsimma area
Daura	676	Sandy drift on basement	Katsina-Daura area
Shinkafi	-	Red sealing sand	Rabbah plains
Birnin Kudu	-	Sandy drift over iron pan or basement	Kano plains
Kaura Namoda	825	Sandy drift on basement	Zurmi plains
Sada	790	Sandy drift on basement	-
Dogan Daji	843	Sandy drift on basement	-
Rano	728	Sandy drift on basement	Gasau plains
Maru	850	Basement complex soil	Tiga plains
Northern Guinea Savanna			
Tumu	-	Sandy or loamy	Gombe sand stone
Dangora	-	Wetter soil on basement	Karaye plains area
Zuru	1024	Variable basement soil	Malendo plains
Bauchi	1095	Stony sand on basement	Bauchi hills and plains
Daudawa	1082	Sandy loam drift on basement	Gusau plains
Saminaka	1012	Sedentary loam	Lere plains
Maigana	1074	Sandy loam on basement	Galma plains
Soba	1051	Sandy loam on basement	Galma plains
Makarfi	-	Sandy loam on basement	Galma plains
S/B/Gwari	-	Sedentary soil	B/Gwari ridges and plains
Samaru	1100	Sandy loam on basement	Galma plains
Southern Guinea Savanna			
Zonkwa	1493	Soil on basalt	Manchok area
Langtang	1285	Concretionary soil on basement	Wamba - Langtang Zone
Kontagora	1174	Deep sandy clay loam on Nupe sand stone	Kulfo plains
Mokwa	1170	Deep sandy clay loam on sand stone	Niger-river plains
Yandev	1331	Sand on basement and sand stone	Yandev area

samples tested exhibited a pH in water less than that in $CaCl_2$ solution. This indicated that these samples possessed a net negative charge in the colloidal complex. Only 10 out of 313 samples were sufficiently acidic for their pH values to fall below 5.0 in water. There was little difference in soil pH in soils of different vegetation zones (Table 1) The pH did not limit production in these soils provided that management avoided extreme soil acidification under intensive cultivation.

Exchangeable Cation

Total exchangeable cations were highest in Northern Guinea Savanna soils and decreased to a comparatively low value in the soils of the Sudan Savanna and Southern Guinea Savanna (Table 2). Predominance of sand in Sudan Savanna and Southern Guinea Savanna soils is considered to be responsible for their low cation contents. Amount of exchangeable cations increased steadily with the clay content.

Exchangeable Ca and Mg behaved in the same way as total exchangeable cations in all the soils. The values of exchangeable Ca and Mg were highest in Northern Guinea Savanna zone and decreased in the Sudan and Southern Guinea Savanna zones due to dominance of sand fraction in the latter two zones.

The mean Ca:Mg ratio was 3.85 and this ratio did not exceed the critical value of 5.0 set out by Horvath and Todd (1968) and as such there seemed to be no imbalance between exchangeable Ca and Mg in these soils. Although mean exchangeable Mg contents (Table 2) were much higher than the critical range of 0.20 to 0.42 meq/100 g (Anon, 1978), the mean Mg/K ratio was 2.74 which is slightly higher than the critical exchangeable Mg/K ratio of 2.5 as given by Pratt et al. (1957). Thus Mg was the most vulnerable cation whose availability may create problems in continuous and intensive cultivation.

Exchangeable K content was very different from those of Ca and Mg. Their contents were low (0.32 Meq/100 g) as shown in Table 2. The percent of samples with critically low K value (less than 0.13 Meq/100 g as reported by Sobulo, (1973) were 40 and 30% respectively in the Sudan and Northern Guinea Savanna zones. Only 10% samples in Southern Guinea Savanna fell below the critical limit of 0.13 Meq/100 g exchangeable K. This is in line with the observation of Wild (1971) and Singh and Balasubramanian (1983) who reported that exchangeable K contents of savanna soils are low. Balasubramanian et al. (1984) and Iwnafor (1979) observed a positive correlation between exchangeable K and silt content in Savanna soils of Nigeria.

Effective Cation Exchange Capacity

The effective CEC was obtained by summation of exchangeable cation and exchangeable acidity. Since the present trend is to use the effective CEC rather than neutral CEC for fertility evaluation in tropical area (Coleman et al. 1959) only effective CEC has been presented in the table (Table 2). Effective CEC was highest in Northern Guinea Savanna soils followed by the Southern Guinea Savanna and the Sudan Savnna soils in decreasing order (Table 2). The effective CEC values increased with increasing clay and silt in all the soils.

Organic Carbon, Total N and C/N Ratio

Organic carbon ranged from 0.18 to 1.53 percent in different ecological zones of Nigeria savanna with a mean value of 0.57%. Organic carbon content increased from Sudan Savanna to Southern Guinea Savanna soils (Table 2) and this is mainly due to the increasing organic matter production with increasing rainfall from North to South in the Savanna region. The low level of organic matter in Savanna soils was due to their predominantly sandy nature and from the relatively low rainfall (Jones, 1973). Very significant correlations between organic carbon and total nitrogen, resin-p, exchangeable Ca and effective CEC were observed in Savanna soils of Nigeria by Balasubramanian *et al.* (1984). This emphasizes the important contribution of organic matter to effective CEC, total N and available P in savanna soils.

Total nitrogen content ranges from 0.02 to 0.15 percent with the mean value of 0.05 percent. Total-N values also increased with increasing rainfall and clay content (Table 2).

The C/N ratio ranged from 5.8 to 22.0 with a mean value of 10.1. As observed by Adebayo and Akaeze (1976), the narrow C/N ratio of Savanna soils may be due to high rate of organic matter decomposition.

Table 2 Range and mean values of soil properties of savanna soils of Nigeria (0-20 cm)

	pH ($CaCl_2$)	Exchangeable Bases (Meq/100g) Ca	Meq	K	Eff. CEC (Meq/100g)	Org. C. (%)	Total-N (%)	C/N Ratio	Avail. P (ppm)	Mechanical Analysis (%) Clay	Silt	Sand
						Sahel - Sudan - Savanna						
Range	4.3 to 6.7	1.3 to 5.3	0.4 to 2.0	0.09 to 0.83	1.60 to 4.81	0.18 to 0.60	0.02 to 0.05	5.8 to 8.9	1.3 to 9.0	4 to 20	4 to 39	60 to 96
Mean	5.4	2.0	0.6	0.21	2.81	0.24	0.03	7.0	3.9	6.3	12.1	86.0
						Northern Guinea Savanna						
Range	4.6 to 6.9	0.8 to 7.1	0.4 to 2.6	0.12 to 0.89	2.00 to 10.31	0.33 to 1.00	0.03 to 0.08	7.1 to 12.0	2.0 to 8.0	8 to 30	12 to 40	45 to 70
Mean	5.3	4.5	1.2	0.35	6.10	0.50	0.05	9.0	3.0	16.0	26.8	57.2
						Southern Guinea Savanna						
Range	5.1 to 6.7	0.6 to 4.8	0.3 to 2.1	0.12 to 1.00	1.81 to 9.11	0.51 to 1.53	0.06 to 0.15	8.1 to 22.0	2.1 to 10.3	10 to 22	6 to 19	50 to 90
Mean	5.6	3.5	0.8	0.39	5.12	0.97	0.07	14.3	4.1	11.3	9.1	75.5

Available-P

Several methods are being used to determine the available-P in Nigerian soils. The present method (Bray-1) is very commonly used to estimate the available-P of soils in Nigeria. The available-P in Savanna soils ranged from 1.3 to 10.3 ppm with a mean value of 3.7 ppm. There was no definite trend in available-P content with varying ecological zones (Table 2). The values of -P were low to medium range in most of the Savanna soils which needed frequent application of Phosphate to maintain the optimum level of P in soil to support crop yields.

Mechanical Composition

Most of the Savanna soils in Nigeria are sandy with sand percent ranges from 45 to 96 with a mean value of 72.9 percent. About 25% of the soil samples tested in this study contained 90 to 95 percent sand. Soils in Sudan Savanna were highest in sand content followed by Southern Guinea Savanna and Northern Guinea Savanna.

Silt content in Northern Guinea Savanna soils were highest and decreased in Sudan Savanna and Southern Guinea Savanna (Table 2).

Clay content was generally low in most of the Savanna soils of Nigeria, the range being between 4 to 30 percent with a mean value of 11.2 percent. Clay values were highest in Northern Guinea Savanna soils (Table 2).

Crop Yields in Savanna Zones of Nigeria

Millet (*Pennisetum americanum*)

Millet is one of the important cereal crops of the Savanna zones of Nigeria, occupying about 5 million hectares. Under traditional farming, it is usually grown in mixture with sorghum and harvested early in the season. Yields under such conditions are usually about 600 kg of grain. Yields up to 2000 kg or more per hectare can easily be obtained with sole crop of millet cultivation if improved practices of millet cultivation are adopted. Some of the factors which contribute to millet yields include early or timely planting, good husbandry (close spacing and timely weeding etc.), improved variety, adequate and balanced fertilization and early thinning.

Results presented in Table 3 on millet yield indicate that with improved crop husbandry, yields up to 870 to 887 kg/ha can be obtained without any fertilizer. With the application of N, P and K, yields up to 1665 to 2250 kg/ha were obtained in either Sudan or Northern Guinea Savanna zones. The findings of Balasubrawanian and Mokwunye (1978) and Singh *et al.* (1983) also indicated a positive response by millet to fertilizer application in Sahel-Sudan and Northern Savanna zones of Nigeria.

With the development of new varieties and also some hybrids, few advance trials were conducted in order to find out the response to fertilizer application. Results presented in Table 4 indicate that hybrid millet responded favourably to fertilizer application.

Sorghum (*Sorghum bicolor* (L.) Moench

Sorghum is one of the most widely cultivated cereal crops and the most important food in the Savanna areas. It accounts for about 50% of the total

Table 3 Mean yield of Millet in different ecological zones of Nigeria

Ecological Zone	No. of Trials		Yield (kg/ha)				
			No Fertilizer	60kg N	30kg P_2O_5	60kgN+ 30kg P_2O_5	60kgN+30kg P_2O_5+ 30kg K_2O
Sahel and Sudan Savanna	22	Mean	867	1304	1125	1491	1665
		Range	235-1413	538-2490	451-1960	960-2880	1140-2960
Northern Guinea Savanna	15	Mean	870	1687	1200	2029	2250
		Range	587-1699	931-2846	721-2012	1212-2846	1336-3165

cereal production (including rice maize, millet and wheat) and occupies 46% of the total land area devoted to cereal production in the country.

The area devoted to sorghum has increased by about 25% over the last two decades from 2.6 million hectares in 1959 to an estimated 6.0 million hectares in 1981. Production has equally increased from a very low of 2.6 million metric tons in 1960 to over 8.9 million metric tons in 1982.

Most of the indigenous sorghum in Nigeria are tall (4.5 m), late maturing, taking between 150-180 days to reach maturity and low yielding (600 to 800 kg/ha). They also respond poorly to increased fertilization. However, with the improved variety of medium to shorter duration it was observed that yields could be improved substantially with proper management and fertilizer application. Under experimental conditions, 3 to 6 times higher yields of sorghum have been obtained compared to yields obtained under traditional conditions (Goldsworthy, 1970 and Norman, et al.1976).

In Nigeria, it has been demonstrated that most of the improved dwarf and semi dwarf varieties of sorghum respond very well to nitrogen application. The recent report of fertilizer recommendation by Singh *et al.* (1983) reveals that application of 64 kg N/ha will be sufficient in Sudan and Northern Guinea Savanna zones of Nigeria.

Application of P and K (Tables 5 and 6) indicate that yield of sorghum could be improved in both Sudan and Northern Guinea Savanna Zones. Application of 36 kg P_2K5 and 25 kg K_2O will increase the yield by approximately 50 and 20% respectively over no application of P and K. Earlier findings of Singh (1981) and Singh *et al.* (1984) indicated that response of sorghum to K in Savanna zones of Nigeria was variable and it was always dependent on the K status, length of cultivation and crops and cropping practices.

Groundnut (*Arachis hypogaea*)

Groundnut is an important industrial, cash and food crop in Nigeria. During 1950's and 1960's groundnut production in Nigeria was its highest providing for both internal consumption and export market. These bumper years were followed by a downward trend in production during 1970's. This was due to series of droughts, poor rainfall distribution, an epidemic of groundnut rosett virus disease in 1975 and an increasing occurence of groundnut rust disease from 1976.

The production zones lie within lat. 8°-13° N, the semi-arid Savanna zone of the country. The soils in the area are pre-dominantly Alifisols and Inceptisols derived mainly from the aeolian material overlaying Basement

Table 4 Mean yield of different improved varieties of Millet under different N levels and in different ecological zones of Nigeria

N (kg/ha	Yield of different varieties (kg/ha) Gero hairy	Dwarf composite	Gero early	Hybrid	Ex-Borno (as check)
Sudan Savanna					
0	1460	1340	1020	1300	1020
50	2020	1880	1440	2360	1940
100	2440	2580	1840	2760	2020
L.S.D. (5%) Nitrogen	201				
Variety	217				
Northern Guinea Savanna					
0	533	800	533	867	567
50	2033	2100	1333	2233	1667
100	1700	1800	1800	2333	1667
L.S.D. (5%) Nitrogen	210				
Variety	223				

Table 5 Response of Sorghum to P in presence of optimum level of N and K in Savanna zones of Nigeria (1977-1981)

P_2O_5 (kg/ha)	Yield (kg/ha) Sudan Savanna Mean	Range	Northern Guinea Savanna Mean	Range
0	1241	450-1979	1173	1062-1280
18	1697	645-2591	1602	1257-2047
36	1898	975-2838	1998	1434-2675
54	1955	1020-2935	1994	1396-2888
L.S.D (5%)	198		207	
No. of replicated trials conducted	18		15	

complex (Harpstead, 1974). The productivity potential of soils tend to decrease progressively Northwards from lat. 7° to 13° (the Southern most limit of the Savanna zone). Most of the groundnut production comes from the small holdings of peasant farmers who, for the most part, use only low doses of phosphate fertilizer on the crop.

Table 6 Yield response of sorghum to K in presence of optimum level of N and P in Savanna zones of Nigeria (1977-1981)

kg K_2O/ha	Yield (kg/ha) Sudan Savanna Mean	Range	Northern Guinea Savanna Mean	Range
0	1488	652-2285	1562	1301-1955
25	1765	776-2540	1674	1247-2268
50	1940	889-2706	1763	1313-2367
L.S.D. (5%)	201	-	108	-
No. of replicated trials conducted	18	-	15	-

Results presented in Table 7 deal with the effect of the phosphate application on groundnut yield and indicate a good yield response in the two ecological zones of Nigeria (Sudan and Northern Guinea Savanna zones). Yayock (1979), Singh (1984), Lombin and Singh (1985) showed that there were significant yield responses to applied P up to 54 kg P_2O_5/ha in Savanna zones of Nigeria.

The degree of response to applied P is variable depending on the intensity of cultivation, previous fertilizer application and P status of the soil. Until

Table 7 Effect of Phosphate application on groundnut yield in Savanna zones of Nigeria (1977-1981)

P_2O_5 (kg/ha)	Yield (kg, pods/ha)			
	Sudan Savanna		Northern Guinea Savanna	
	Mean	Range	Mean	Range
0	928	619-1169	1380	1247-1606
18	1125	807-1336	1706	1396-1933
36	1251	1137-1402	1860	1582-2092
54	1363	1257-1480	2019	1588-2413
L.S.D (5%)	126	-	153	-
Total No. of experiments conducted	30	-	20	-

1984, no emphasis was given on the use of potash for groundnut cultivation in the Savanna zones of Nigeria. The recent fertilizer recommendation made by Singh (1984) indicated a positive and significant response of groundnut to K application up to 25 kg K_2O/ha. Most of the Savanna soils in Nigeria are likely to become deficient in available K under intensive cultivation, non supply of potassium through fertilizer and non return of crop residues. This observation has been made by several researchers in the past (Goldsworthy, 1964, Wild 1971, Jones and Wild 1975, Singh and Balasubramanian 1979, and Lombin and Singh 1985). The present data (Table 8 indicates a significant positive response to K application in Sudan Savanna and Northern Guinea Savanna zones of Nigeria.

Table 8 Effect of potassium application on groundnut yield in Savanna zones of Nigeria (1977-1981)

K_2O (kg/ha)	Yield (kg, pods/ha)			
	Sudan Savanna		Northern Guinea Savanna	
	Mean	Range	Mean	Range
0	959	723-1165	1538	1209-1814
25	1102	836-1340	1751	1369-2072
50	1192	938-1433	1853	1502-2084
L.S.D (5%)	190	-	173	-
No. of experiments conducted	30	-	20	-

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34 Solving the problem of soil fertility in the African semi arid zone.

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Abstract The basic characteristic of the arid climate is the rainfall distribution and intensity. The rainfall intensity is characterised by rain coming in few heavy showers of short duration leading to considrable run-off. The relative humidity is low and may be less than 30%. There is high solar radiation and potential evapotranspiration. The intensity of light is high and may be up to 75-90% of the possible sunshine. Radiation of 140-190 KCal/cm is very common. The temperature ranges from 100°F in the day to well below 50°F in the night thereby producing a diurnal effect. Soils acquire and loose heat rapidly, and dust-laden winds are of high velocity and unpredictable direction.

This harsh and aggressive climate is largely responsible for soil fertility problems of the land. These include the inherent nature of the soils parent material, low organic matter, low clay content, low activity of the dominant clay minerals, few exchange sites and sometimes domination by the coarse well-drained sandy soils of the dunes. Because of their age, the soils have very weak genetic horizons. In addition, as the density of the vegetation decreases from the Guinea to the Sahelian zone, addition of organic matter to the soil progressively decreases.

In the absence of thick vegetation cover, recycling of nutrients from the soil to the vegetation and back to the soil through litter fall does not occur under Sahelian conditions. Annual burning of grasses, debris and crop wastes, total removal of crop residues for use and a source of fuel, roofing and fencing, the non-return of crop residues into the field, over grazing and the activities of termites adversely reduce the levels of organic matter, total N and S in the soil.

Research efforts have been focussed on developing suitable farming systems that would help in water and land conservation. Depleted organic matter content of the soils have been replenished by the use of inorganic and organic fertilizers (green manures, composite, farm yard manures) and complete return of crop residues. Agroforestry has also helped to minimise nutrient depletion in addition to reducing the effect of the harsh climate.

The solution to most of these problems also depends largely on the utilization of appropriate farming systems. Fertilizers must be applied, after appropriate soil analysis, to determine the nutrient status of the soil. Other promising farming systems include intercropping, relay cropping, sequential cropping, and alley cropping. There is also need to intensify research on the role of both herbaceous and shrub legumes on continuous arable crop production, organic matter management, the use of organic material for biogas and biofertilizer, shelter belt for firewood production and organic recycling.

Introduction

The basic characteristic of the arid climate is the rainfall distribution and intensity. Martonne (1961) defined dry climate in relationship to precipitation and temperature. This relationship is expressed as the "aridity-index" which can refer to a selected dry period of a few days, a week, a month, a season or a year. The rainfall intensity is characterised by rain falling in a few heavy showers of short duration leading to considerable runoff. Gaussen (1954), from his studies of natural vegetation defined arid month and aridity in terms of mean monthly precipitation (cm) and mean monthly temperature (°C). The temperature of these areas ranges from 100°F in the day to well below 50°F in the night, the soils therefore acquire and loose heat rapidly and may reach a temperature of about 93°C.

Thornthwaite (1948) defined arid zones on the basis of two elements: water supply in the form of precipitation and water needs resulting from evapotranspiration. He concluded that aridity occurs anytime rainfall is less than potential evapotranspiration and semi-aridity results when the two are approximately equal.

In all the above definitions of arid climate, rainfall has been the singularly identified climatic factor responsible for the problems of the arid and semi-arid zones. While this may be partially true, it is not also uncommon to have unfavourable effects from the other factors of the climatic and vegetational environment. For example, there is high solar radiation, while the intensity of light is high and may be up to 75-90% of the possible sunshine. Radiation of 140-190 KCal/cm is very common. Temperature and the light effects interact to affect the water regime of the soil. Equally important is humidity. Humidity is the state of the atmosphere with respect to the gaseous form of water. Absolute humidity is not always low in the arid zone but the relative humidity tends to be low and may be less than 12%.

Winds in this area are also characterised by their frequency and high velocity which are partly due to considerable convention during the day. The sparse vegetation cannot reduce wind velocity. The prevailing winds of the region are the trade winds, which bring rain to the coastal districts. In West Africa the wind is sometimes dust-ladden and is called harmattan.

Agriculture is entirely dependent on rainfall, therefore the crops in this zone suffer from severe moisture stress. Moisture stress in crops can be reduced by irrigation in the dry season, but the physical conditions of most of the soil in the zone militate against successful irrigation.

Soil fertility problems

The harsh and aggressive climate is largely responsible for the fertility problems of the land. The soils of most of this area are sandy especially at the surface. This sandy nature of the soil is mostly responsible for the poor water-holding capacity, very little capillarity movement, rapid water infiltration, low retention of nutrients, little or no cohesiveness or plasticity, high specific temperature, but excellent aeration hence they are easily tilthed. When irrigation is practised, these soils have greater permeability to water and the lower ability to retain cations reduces salinity problems. Though the water-holding capacity is low, the water is easily made available to plants than in heavy loams and clays.

An analysis of selected soils from the semi arid regions revealed that total N was high in soils of loamy texture followed by clay, loamy sand, sandy loam and sandy clay loam in that order (Table 1). Total N ranged from 11.80 to 88.44 ppm organic carbon ranged from 0.069 to 1.637 and C.N. ratio ranged from 3.05 to 33.69.

Table 1 The relationships between soil textural classes and soil fertility status of selected soils of semi-arid zone

Characteristics	Loamy sandy	Sandy loam	Sandy clay/loam	Loam	Clay
Proportion in total number of soil samples studied (%)	40.0	22.5	15.0	10.0	10.5
Total N% minimum:	0.0218	0.0321	0.0321	0.0673	0.0338
Maximum	0.0993	0.1204	0.0874	0.1023	0.1064
Mean	0.0649	0.0641	0.0610	0.0810	0.0660
Available N (ppm)					
Minimum	11.80	12.80	17.30	38.20	27.20
Maximum	85.40	87.80	68.20	81.20	73.40
Mean	38.10	42.71	39.22	65.73	44.52
Available P (ppm)					
Minimum	1.6	3.6	40	3.6	2.0
Maximum	24.0	38.0	19.2	28.0	16.0
Mean	2.1	6.2	7.6	10.6	4.4
Exchangeable K Meq/100g					
Minimum	0.06	0.05	0.08	0.09	0.14
Maximum	0.11	1.03	0.17	0.11	0.74
Mean	0.08	0.21	0.13	0.10	0.47
Organic carbon (%)					
Minimum	0.069	0.157	0.098	0.627	0.290
Maximum	0.443	0.731	1.3224	1.637	1.139
Mean	0.302	0.389	0.489	1.041	0.578
C:N. ratio					
Minimum	3.16	3.25	3.05	9.31	4.50
Maximum	8.40	14.88	15.14	16.00	33.69
Mean	4.59	6.31	7.27	12.53	11.48

Available P of the studied samples ranged from 1.6 to 38.0 ppm with a mean value of 3.9 ppm. The available P content of the semi-arid and arid regions is very low due to low total P content, high P-fixing capacity of 1:1 silicate clays and Fe and Al oxides. The soil is calcarious with low organic matter contents.

The CEC varies from 2.4 to 50.4 and the exchangeable Ca content of the sampled soils ranged from 1.0 to 28.4 and about 80% of the samples recorded low amounts of exchangeable Ca. The levels of micro-nutrients such as the Fe and Mn are high relative to that of B, Cu and Zn. The percentage base saturation varied from 51% to 9.67% (Table 2).

In the hydromorphic areas, the mean values of total N, organic carbon, available N and available P were 0.0659%, 0.458%, 42.9 ppm and 10.9 ppm. Also the values of 14.6 meq/100 g soil and 10.88 meq/100 g soil are not uncommon for cation exchange capacity and total exchangeable bases respectively.

The exchangeable cations of Ca, Mg, K and Na had values of 28.4, 8.2, 0.73 and 2.17 meq/100 g soil respectively. Rayar, 1984 also reported values of 4.57% and 76.2 for exchangeable sodium and percentage base saturation.

A quantitative and qualitative analysis of these figures demonstrates that

Table 2 Physical and Chemical Properties of Selected Soils of the Semi-arid Zone

Soil	Total 1%	Organic Carbon %	C:N Ratio	Available ppm N	Available ppm P	CEC meq/100	Exchangeable cations meq/100g Ca	Mg	K	Na	B	Micronutrients ppm Cu	Fe	Mn	Zn	ESP %	BS %	TEB Meq/100g	Soil pH	% Sand	% Clay	% Silt
1	0.0620	0.204	3.29	45.2	3.6	3.4	1.4	1.4	0.05	0.25	0.30	0.60	16.00	35.00	3.80	8.06	91.2	3.10	6.90	90	2	8
2	0.0338	1.139	33.69	38.5	7.2	50.4	28.4	5.2	0.73	2.17	0.20	0.50	14.00	15.00	1.50	5.95	72.4	36.50	6.5	88	4	8
3	0.073	0.244	3.28	29.2	77.2	14.60	9.2	4.2	0.14	0.27	0.30	1.20	25.00	91.00	1.90	1.96	94.6	13.81	5.9	90	2	
4	0.0791	0.714	9.02	60.1	20.0	10.3	5.6	3.0	0.42	0.30	0.25	0.90	10.00	87.00	1.50	3.22	90.5	9.32	5.8	71	16	13
5	0.0721	0.558	7.73	57.9	3.6	8.4	2.8	1.0	0.06	0.24	0.50	1.30	472.00	11.00	1.40	5.85	48.8	4.10	6.20	82	8	10
6	0.0641	0.292	4.55	28.1	4.0	5.8	2.2	0.6	0.07	0.12	0.40	0.70	15.0	30.0	2.20	4.01	51.6	2.99	5.6	82	2	16
7	0.0637	0.627	9.31	39.2	19.2	12.8	6.6	3.6	0.09	0.25	0.45	0.80	12.00	20.0	2.50	2.37	82.2	10.54	5.6	88	4	8
8	0.1204	0.392	3.25	87.8	4.0	4.2	1.0	0.8	0.05	0.14	0.35	0.60	14.00	18.0	1.40	7.03	47.4	1.99	6.2	88	8	13
9	0.0476	0.400	8.40	17.7	7.2	4.5	2.6	1.4	0.08	0.27	0.65	1.00	126.00	14.0	1.00	6.21	96.7	4.35	6.7	72	4	23
10	0.1064	0.611	6.21	73.4	11.6	44.0	19.0	8.2	0.14	1.10	0.85	3.30	105.00	101.1	2.80	3.87	64.7	28.44	6.7	67	17	15

some of the soil fertility problems of this zone are chemical in nature. In regions of low rainfall, the colloidal complex of the soil is generally dominated by the common basic cations of Ca, Mg and Na. The colloidal complex tends to retain these elements leading to alkalinity.

On hydrolysis and dissociation of some salts like carbonates, bicarbonate and biphosphates, there is high release of hydroxyl ions in excess of hydrogen ion leading to alkalinity. The anion exchange capacity decreases with increasing pH. For this reason, the agricultural soils of the arid regions, with relatively high pH, have a low capacity formation absorption. Other soil chemical problems of this zone include phoshate deficiency because of fixation, few exchange sites and low acidity of the dominant clay minerals.

The clay content of the soil is also generally low and there is little utilizeable profile depth because of the shallow soil. The humus content is low and there is high susceptibility to droughtness and wind erosion.

In the Semi Arid zone the amount of organic matter is low, the depth is shallow and thin (figure 1).

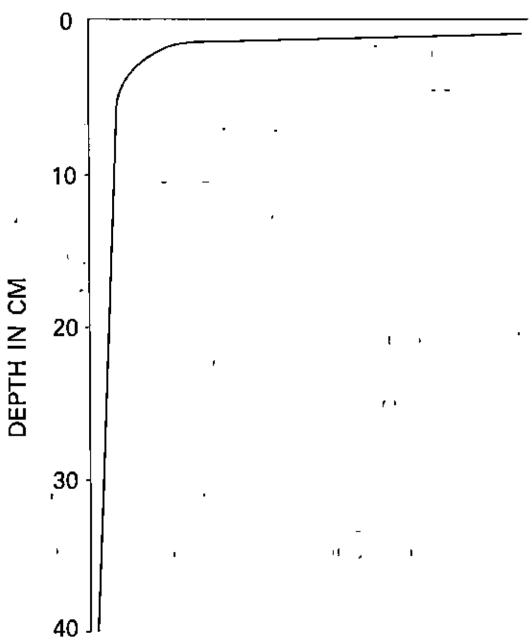

Figure 1 Changes in soil organic matter in soils of semi arid Africa

The influence of soil organic matter on soil nutrients is remarkably high. In all cases, P, K, Mg, Ca and CEC are highly correlated with organic matter level of the soil (Table 3), this in turn affects crop yield (Tables 4 and 5).

Maintenance of soil fertility

Soil fertility maintenance under the subsistence smallholder farming system is by alternating short land cultivation cycles with a long period of fallow to allow for regrowth of vegetation. The vegetation provides litter fall which are acted upon by soil micro-organisms causing degradation and decomposition resulting in the accumulation of organic matter. With increase pressure on land due to population increase and intensification of cropping, fallow

Table 3 Simple correlation coefficient for the relationships between the soil variables and other nutrients.

Soil variable	P	K	Mg	Ca	OM	CEC	% Clay
	Correlation Coefficient						
K	0.632	–					
Mg	0.949**	0.524	–				
Ca	0.927**	0.552	0.987**	–			
OM	0.982**	0.924*	0.982	0.987**	–		
CEC	0.642	0.624	0.926**	0.982*	0.988**		
% Clay	0.604	0.800	0.662	0.632	0.922**	0.574	–

Table 4 Response to Split N by rice as affected by O.M. level

Treatment	O.M. Level	Rice yield* 3%	in Kg/ha 1%
60 KgN	Applied at planting	3,600 b	1,600 bc
60 KgN	Applied at maximum tillering	3,400 b	2,000 b
60 KgN	Applied at booting stage	3,500 b	2,400 b
60 KgN	Applied in 2 equal doses at planting and booting stage	3,500 b	3,400 a
60 KgN	Applied in 3 equal doses at planting maximum fillering and booting stages	4,000 a	3,600 a
No. N	Applied	3,000 bc	1,000 c

* Number within Column followed by the same letter are not significantly different (P = 0.05)

Table 5 Effect of different levels of O.M. on N response and yield of the Ife Brown Cowpea

Treatment	0.5%	1%	Soil O.M. 2%	3%	5%
No N	800 c*	1,200 b	1,700 a	1,750 a	1,800 a
10 Kg N/ha	1,300 b	1,650 b	1,800 a	1,200 a	1,750 a
20 Kg N/ha	1,850 a	1,600 a	1,750 a	1,800 a	1,700 a
50 Kg N/ha	1,670 a	1,700 a	1,800 a	1,650 a	1,800 a
100 Kg N/ha	1,750 a	1,800 a	1,800 a	1,750 a	1,800 a

* Number within columns followed by the same letter are not significantly different (P = 0.05).

periods are reduced and the provision of plant nutrients through litter fall is drastically reduced.

Annual burning of fields and fallows during the dry season is a common practice. Burning helps to clear the land of weeds, bush growth and debris in order to facilitate cultivation.

Frequent burning of fields leads to the physical and biochemical degradation of the soils (Charrean, 1974). Besides, the burning of vegetation causes considerable loss of carbon and nutrients in organic form like N and S. Although the left-over ash retains the nutrient cations and the trace elements, these are not evenly distributed over the entire field.

Moreover the sparse vegetation, high temperatures, high rate of erosion from torrential rain occur within a short period (3-4 months or less) in a year, do not permit organic matter accumulation in this region. Soil fertility maintenance through bush fallowing has not even provided acceptable results because of annual burning of the vegetation.

Certain fast growing tree crops such as *Quercus incana, Tamarix articulata* have been found to be well adapted to the semi-arid region (Table 6). Such trees provides shade to the bare soil thereby reducing soil temperature and the litter falling from them is a good source of organic matter. The organic matter act as a binding agent to the soil and exchange sites for soil nutrients, thus improving soil fertility.

In the zone there are native herbaceous shrub and tree Legumes that have not been actively cultivated, therefore surveys of the zone will be necessary to identify these legumes.

Research should be conducted on mode of establishment, nodulation, rate and ability to fix Nitrogen. The identified legumes can be utilised for green manuring, planted fallow, in situ mulch, live mulch and alley cropping.

Both methods protect the soil from rain wash and the disintegrating nodules are able to release nitrogen to the system.

Another suitable system which can solve the soil fertility problem of this zone is the growing of food crops in alley of shrub legumes by pruning the

Table 6 A list of fast-growing trees and their adaptation to soil climatic zone.

Name	Suitable soil – Climatic zone
Acacia arabica	Alluvial plains and dry zones
Acacia auriculiformis	Wet and coastal zone
Acacia catechu	Dry zone
Albizzia lebbek	Dry zone
Bambusa spp	Dry and wet zones
Cassia siamea	Dry and coastal zones
Casuarina equisetifolia	Dry and wet zones
Dalbergia sissoo	Alluvial plains
Dendrocalamus strictus	Dry and wet zones
Eucalyptus spp	Dry, wet and coastal zones
Grewia oppositifolia	Semi-dry zones
Margosa indica	Dry and wet zones
Morus alba	Alluvial and dry zones
Pongamia glabra	Alluvial and coastal zones
Quercus incana	Dry zone
Tamarix articulata	Dry zone

legumes to serve as source of green manure before planting and in situ mulch during cropping.

Intercropping and relay cropping could provide suitable cropping patterns that would alleviate some of the problems of soil degradation.

Another major factor contributing to the very low nutrient status of the semi arid zone is the inability to utilise available resources at the farmers disposal in soil improvement. Crops grown in the semi-arid zone absorb nutrients from the soil for growth and development (Table 7) and part of these nutrients are stored in the stover (Table 8). Unfortunately these nutrients are not returned to the field.

The residues available are mostly from the cereals millet, sorghum, maize, wheat, and upland rice, cowpea, bambarra groundnuts and stalks of cotton and other fibre crops. The amount of nutrients returned to the soil from the crop residue is dependent on how the latter is disposed after harvest.

In the semi-arid zone there is always strong competition for crop residue between domestic uses and use as manure in the field. These domestic uses include fencing of fields and homestead, roofing of homestead, feeding of cattle and other livestock, for cooking and heating homes. A schemetic representation of the different methods of crop waste management and how each method returns residues to the soil is given in Figure 2.

Table 7 Chemical composition of crop residues and stovers

	N	P	K	Ca	Mg	Zn	Cu	Fe	Mn
			%				ppm		
Maize husk	0.45	0.02	0.26	0.22	0.22	13.44	1.92	3.04	8.32
Cowpea residue	2.07	0.01	0.40	0.03	0.09	4.48	1.28	0.56	0.64
Rice straw	1.74	0.03	0.26	0.04	0.12	6.02	2.56	2.48	0.64
Groundnut residue	1.51	0.03	0.26	0.02	0.98	3.33	0.64	1.12	1.28
Soybean residue (stover, husk)	1.57	0.03	0.36	0.03	0.05	6.64	1.28	2.80	0.64
Maize stem	1.90	0.05	0.68	0.17	0.12	8.90	3.84	5.44	4.48
Sorghum straw	1.29	0.04	1.60	0.14	0.09	6.14	1.92	3.76	3.20
Cotton wool stalk	1.97	0.03	0.47	0.12	0.07	7.04	2.56	2.48	1.92

Table 8 Estimated amount of nutrients removed by various arable crops in the semi-arid region in Kg/ha

Crop	N	P	K	Ca	Mg	Zn	Cu	Fe	Mn
Maize	4.5	0.12	0.65	7.0	0.6	0.0134	0.0019	0.003	0.0083
Cowpea residue	25	2.4	4.0	5.3	2.1	0.0180	0.0052	0.0224	0.026
Rice straw	10.4	0.8	4.0	6.2	2.0	0.036	0.0160	0.0150	0.00384
Groundnut residue	20.0	1.2	3.6	4.2	2.0	0.0024	0.00512	0.0112	0.0024
Maize stem	30	1.0	12.2	11.9	0.84	0.0623	0.0269	0.0379	0.0314
Sorghum straw	26	1.4	30	11.2	3.2	0.049	0.0154	0.0304	0.0256
Cotton wool stalk	47	1.5	6.1	6.0	0.65	0.0352	0.0128	0.0124	0.0096

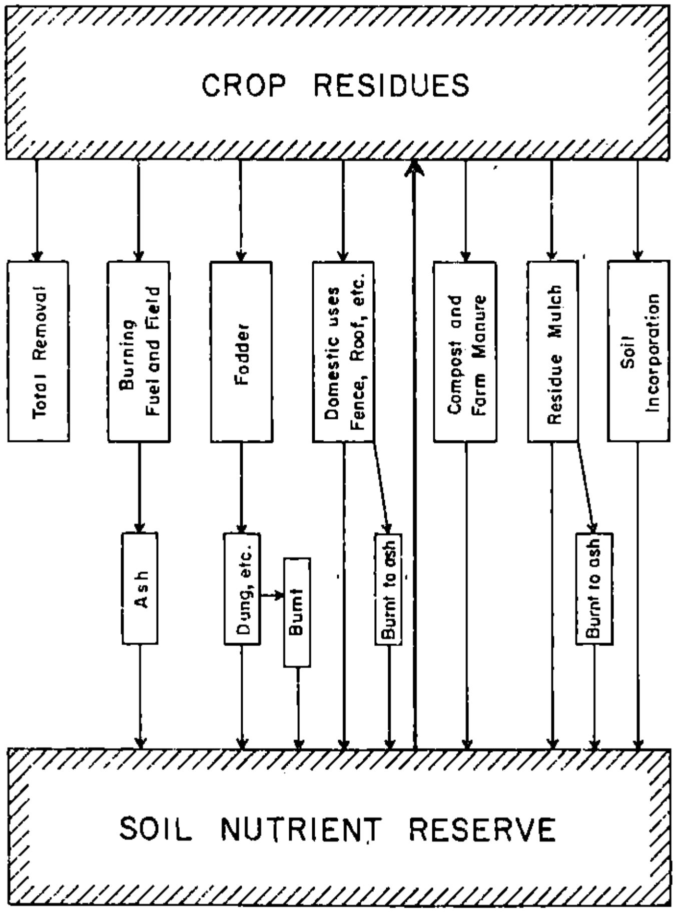

Figure 2 Nutrient recycling between crop residues and soil
Source: FAO Soils Bulletin 43

Complete removal of residues depletes the soil of all nutrients particularly cations. In addition, organic matter content decreases drastically (Table 9) since organic matter affects both physical, chemical and biological properties of soils. Soil management practice in the semi-arid zone should therefore recognise incorporation of crop residue. This decreases the rate of drain of nutrients from the soil reserve, induces beneficial changes in the physical, chemical and biological properties of soils through the build-up of soil humus.

Firewood production

To reduce pressure on stover (crop residue) firewood production should be encouraged. In this zone, there is undulating topography, and poor agricultural land, which should be identified through soil surveys and land capability maps. Areas of steep slope and marginal lands should be used for fast growing trees and shrubs that have regrowth potential and to serve as wind breaks and shelter belts. Selective harvesting and thinning should be employed in their harvesting and such trees can be used for producing charcoal and firewood.

Table 9 Effect of residue treatment on changes in top-soil chemical properties (after Jones 1976).

	Treatment			Change in			
	Organic %	Total N%	pH	Exchangeable inons Meq/100 gm Ca	Mg	K	Total
Burn	−0.022	−0.000	−0.16	+0.01	−0.005	+0.007	+0.01
Incorporate	−0.003	+0.001	−0.03	+0.01	−0.005	−0.005	−0.01
Remove	−0.24	+0.000	−0.32	+0.03	−0.044	−0.085	−0.10
S.E.	0.008	0.002	0.03	0.03	0.007	0.006	0.04

Biogas and biofertilizer production

Animal wastes can also be processed through anaerobic fermentation in biogas plants to produce methane gas for many uses including domestic and industrial cooking and manure. The spent slurry left over after gas production is rich in nutrients and forms good quality manure.

Organic matter recycling

Organic recycling is the return of all unconsumed organic residues and all natural organic manures, to the soil to support crops and animal production. The term also covers the deliberate production of organic material for use as a soil additive and according to FAO (1980) represents cycling rather than recycling of organic materials. The importance of recycling organic material is to conserve the nutrients and energy contained in them and to take the advantage of the favourable effects that organic materials may have on soil physical, chemical and biological conditions for plant growth.

Tonnes of organic materials consisting of urban, industrial and human wastes are produced in the zone annually. Sokoto State in Nigeria for example generated an estimated 2 million tonnes from industrial and urban waste while the total estimated inorganic fertiliser utilised was 80,000 tonnes (Agboola et al 1981). This means that a lot of money can be saved and soil physical and chemical properties improved through organic material recycling. It is estimated that the amount of wastes produced annually in the semi-arid zone of Africa contains about 70 million tonnes of N.P.K. representing about fifteen times the amount of nutrients consumed in mineral fertilisers (4.2 million tonnes of NPK).

Recycling of organic wastes in an integrated scheme such as crop – animal – fish is needed to solve the problem of soil degradation in this zone.

A scheme on organic material recycling is necessary in this region, with organic wastes being utilised in the following ways.

Manure

Animal waste is best utilised as manure. Manure production per animal per year is estimated at 8 tonnes for cattle, 2 tonnes for pigs and horses, 300 kg for sheep and goats and 12 kg for fowls. These could be converted into farm yard manure (FYM) (FAO, 1980).

Rural compost

The major source of rural waste are city waste, domestic solid wastes, dried or green leaf litters. Systematic collection and decomposition of these wastes in piles or pits is called compositing; fresh manure or night soil is sometimes added to these wastes to activate the natural biochemical process.

The introduction of fertilizer from organic materials to this region will contribute to the physical, physico-chemical and nutritional aspects of soil fertility in the region. In addition to supplying the major nutrients N, P and K and some micro-nutrients, FYM will also improve the physical and acid state of the soil. Research conducted in the semi-arid region of northern Nigeria on the effects of FYM on groundnut showed that the use of FYM with inorganic fertilizer significantly increased pod yield of groundnuts (Table 10).

Table 10 Effect of farm yard manure and N on the yield of groundnut

Treatment	Pod yield Kg/ha	Increase over control %
1. Control. No manure and fertilizer	2346.5	–
2. FYM at 10t/ha	2462.5	5.05
3. FYM at 15t/ha	2456.0	4.8
4. FYM at 20t/ha	2909.0	24.1
5. FYM 10t/ha + 20kgN + 40kg P_2O_5/ha	2961	26.75
6. FYM 15t/ha + 20kgN + 40kg P_2O_5/ha	3048	30.25
7. FYM 20t/ha + 20kgN + 40kg P_2O_5/ha	3177	35.9
8. 20 Kg N/ha + 40kg P_2O_5/ha	2889	23.55

Land preparation

Soil fertility destruction starts with land clearing which is the first farming operation. The farmer does manual clearing which is labour intensive; in some cases, the field is just set on fire. Recently mechanical clearing has been advocated and this is spreading and thousands of hectares have been rendered useless for agricultural production. Table 11 gives an indication of nutrient problem being created by mechanical clearing.

Table 11 Effect of mechanical clearing on some soil nutrients

Sample No	Soil OM %	PPpm	K	Ca	Mg	Zn	Cu	B
			Meg/100gm				ppm	
801 Control	1.2	4.3	0.54	2.0	1.4	2.1	3.2	0.6
804	Trace	0.41	0.12	0.7	0.3	Trace	1.0	Trace
806	0.52	0.78	0.11	0.3	0.3	Trace	0.9	Trace
808	0.31	0.83	0.09	0.3	0.4	1.0	0.7	Trace
810	0.21	1.04	0.08	0.2	0.4	Trace	0.2	Trace
812	0.20	Trace	0.30	0.2	0.3	Trace	0.2	Trace
815	0.22	0.6	0.20	0.4	0.2	Trace	0.1	Trace

After land clearing, the next farm preparation that affects soil fertility is land preparation, planting and fertilizer application. It has always been assumed that tractorisation is the only answer to increasing agricultural production. The technology for these operations has been developed elsewhere for soils with very deep and high soil organic matter, but this technology is far ahead of the technological competence of the tropical farmer. Tractorisation has seriously aggravated soil fertility degradation in the semi-arid zone where it is responsible for nutrient leaching, silting of rivers, soil wash, soil compaction, increase runoff, water and wind erosion and clay pan formation. To solve this problem, minimum and zero tillage operation has been found to increase crop yields by about 10%. In such an area the date of planting has been found to be crucial, since all planting has to be completed within 15 days. Zero tillage involves the use of herbicides therefore research should be directed at developing appropriate methods to use herbicide in multiple cropping systems.

Furthermore, appropriate technology tools for land preparation, seed bed preparation, planting and fertilizer application under minimum or zero tillage system should be developed. Animal traction should be developed and improved. Prospective farmers are being encouraged to open up large tracts of land without corresponding soil conservation measures. In my view, small hectares of well-managed and intensively cultivated arable land can generate food security. Large scale arable crop production continuously using large tracks of land cause serious land degradation, (soil erosion, soil fertility deterioration) and at times, total crop failure.

In the tropics, soil fertility problem created by mechanical land clearing is the greatest head-ache for soil fertility management, therefore in solving the problem of soil fertility, it is better to resolve the problem of land clearing.

Soil fertility evaluation and management

Soil fertility is measured by its capacity to support the climax population of plants and animals above ground and the fauna below ground. This is further indicated in reference to the nutrient supplying power of the soils in terms of amount and proportion. The productivity of soils is the ability of a soil to adequately support plants growing on it.

Although fertility and productivity are two separate entities, a soil may be fertile, yet become unproductive since productivity is represented as a combination of factors of fertility and the immediate environment. An unproductive fertile soil can be rendered very productive through good soil management practices.

Over the years, the main management practices used in improving fertility of the semi-arid zones has been bush fallowing. Recently, efforts have been made by research institutions to develop patterns of fertilizer use for various crops and recommending adequate fertilizer combinations and quantities to farmers for optimum crop yields.

Presently the accepted fertilizer recommendation is the blanket fertilizer recommendation for crops given in Table 12.

The fertilizer materials currently in use for arable cropping in Nigeria are the 15-15-15, 25-10-0 compound fertilizers: Others are the straight fertilizers namley ammonium sulphate, single super phosphate and muriate of potash. These recommended fertilizers supply only one or two nutrients which is not satisfactory, since it has been found that where tropical soils are continuously cropped for long periods with incomplete fertilizer, the levels

Table 12 Blanket fertilizer recommendation in the semi-arid zone of Northern Nigeria

Crop	Fertilizer recommendation
Rice	80kgN + 33kg P_2O_5/ha.
Guinea Corn	33kgN + 25kg P_2O_5 or 72-100kgN; 50-75kg P_2O_5 + 50kg K_2O/ha for improved varieties.
Millet	13kg N + 11kg P_2O_5 or 50kgN + 18kg P_2O_5 + 15kg K_2O/ha for improved varieties.
Maize	400kg/ha of 15-15-15 compound
Wheat	100kg/ha N + 45kg/ha P_2O_5 for sandy soils.

of exchangeable cations, Ca, Na and K drop drastically and the soil becomes increasingly acid.

Fertilizer application without soil testing may increase yields temporarily but may compound the problems of soil fertility. On a newly cleared soil for example, the micronutrients are very high. When an incomplete fertilizer is added to the soil, the quantity of the elements N, P and K is increased. Any plant growing on the soil will absorb the added and native NPK, plus other essential nutrients in certain proportion. In the absence of fertilizer plant growth will be small. With the application of fertilizer, there will be more growth, therefore more nutrients will be absorbed. As cultivation continues more of the unapplied nutrients will be required for a high yield. Other nutrients e.g. Ca, B, Mg which are not added because they are absent from the fertilizer formula may limit the yield of crops.

Table 13 presents the physical and chemical characteristics of some Nigerian soils in the semi-arid region. These soils differ considerably in chemical and physical characteristics, therefore a blanket fertilizer recommendation for a specific crop would be unappropriate. Fertilizer recommendations should reflect all these differences.

Table 14 gives the results of an experiment on soil samples collected from the different sites mentioned in Table 13. These soils have different physical and chemical properties, their response to the same amount of fertilizer requires more P, because after about 6 months only 20% of the added P will be available while 25% of the added P will be available to crops planted in Potiskum soil.

The % yield varied from 8–89% to 86.21% when no fertilizer was applied. If 10 ug/ml of P fertilizer is applied, this will increase soil P in all the soils. The soil in Birnin Kebbi wil now have 33 ug/ml applied P. Some amount of P will be fixed.

But the amount that becomes available after P application is controlled by the fixing capacity of each soil, while the soil in Nguru will have 33 ug/ml assuming none of the applied P is fixed.

Okeya (1977) reported that metamorphic rocks, irrespective of the vegetation cover have high capacities to fix added soluble P sandstone and unconsolidated aeolian parent materials fixed less P whereas soils with sandstone parent materials were intermediate. He used fractional recovery (FR) defined as the proportion of the added P that is extracted by an extractant after a period of time to work out the relationships.

Table 13 General characteristics of some soils of semi-arid zones

Soil sample Site	pH	CEC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	S	P	B	Cu	Fe	Mn	Zn	O.M.	Sand	Silt	Clay	Great Soil Group
Birin Kebbi	5.6	1.93	1.40	0.42	0.08	0.20	23.0	7.0	0.30	0.60	16.0	35.0	3.8	0.3	88	2	10	Alfisols
Argungu	5.6	1.48	1.10	0.26	0.04	0.13	19.0	6.0	0.20	0.50	14.0	15.0	1.50	0.18	88	4	8	"
Sokoto	5.9	5.72	4.0	1.7	0.08	0.35	21.0	12.0	0.30	1.20	25.0	91.0	1.09	0.52	82	2	16	"
Gombe	6.20	2.94	2.0	0.58	0.20	0.27	21.0	5.0	0.25	0.9	10.0	87.0	1.50	0.45	82	8	10	"
Danaturu	5.8	2.73	0.80	0.13	0.07	0.12	7.0	4.60	0.50	1.30	472.0	11.0	1.40	0.25	80	10	10	"
Yendev	5.9	3.23	2.30	0.63	0.04	0.16	10.0	4.0	0.17	1.0	28.0	46.0	2.0	1.10	77	10	7	"
Kano	6.20	3.38	2.40	0.64	0.04	0.10	12.50	5.0	0.20	0.9	15.0	25.0	1.6	0.3	75	16	9	Entisols
Potiskum	5.9	2.24	1.60	0.37	0.05	0.18	13.0	4.0	0.30	0.9	12.0	39.0	1.2	0.18	86	6	8	"
Katsina	6.4	2.6	2.0	0.44	0.06	0.17	19.0	16.0	0.45	0.80	33.0	14.0	2.90	0.35	88	2	10	"
Daura	7.1	2.95	2.2	0.59	0.06	0.23	28.0	14.0	0.55	0.20	10.0	2.20	2.50	0.3	92	–	8	"
Gashua	6.5	2.97	2.10	0.64	0.07	0.54	17.0	12.0	0.40	0.70	15.0	30.0	2.20	0.2	88	4	8	"
Nguru	6.90	3.09	1.80	0.64	0.25	0.40	19.0	23.0	0.45	0.0	12.0	20.0	2.50	0.15	90 2	8	"	
Maiduguri	5.9	2.37	1.9	0.71	0.05	0.22	14.0	6.0	0.35	0.60	14.0	18.0	1.4	0.15	90	2	8	"
Gusau	5.2	3.49	2.30	0.68	0.08	0.36	11.0	5.0	0.65	1.00	126.0	14.0	1.0	0.38	76	12	12	Alfisols
Wasasa-Zaria	5.6	4.28	3.10	0.73	0.05	0.30	12.5	6.0	0.20	1.30	8.20	32.0	2.80	0.75	57	32	11	"
Jos	5.8	3.58	2.30	1.00	0.05	0.23	12.5	6.0	0.7	1.40	30.0	25.0	1.5	0.60	71	16	13	"
Bauchi	5.9	7.87	5.9	1.50	0.05	0.22	10.0	9.0	0.17	0.70	31.0	31.0	2.0	1.05	67	19	14	"
Biu	5.80	12.3	8.0	3.80	0.16	0.52	17.0	9.50	0.85	3.30	105.0	101.0	2.80	1.10	28	48	24	"

Table 14 Behaviour of soils to Added P.

Site	Control (gm)	Maximum yield gm	Relative yield %	Soil P in ug/ml	FR
Birnin Kebbi	1.20	4.10	29.27	7.00	0.20
Arugungu	1.85	4.15	44.59	6.00	0.32
Sokoto	2.20	3.85	57.14	12.00	0.12
Gombe	0.35	2.60	13.46	6.00	0.28
Damaturu	0.50	5.45	9.17	4.60	0.27
Yandev	0.55	3.35	16.42	4.00	0.18
Kano	0.75	5.25	14.29	5.00	0.20
Patiskum	0.40	4.30	9.30	4.00	0.25
Katsina	2.50	2.90	86.21	16.00	0.22
Daura	4.20	6.10	82.35	14.00	0.24
Nguru	4.55	5.00	91.00	23.00	0.26
Gashua	2.60	3.45	75.36	12.00	0.28
Maiduguri	1.55	5.55	27.93	6.00	0.27
Gusau	0.74	5.40	13.89	5.00	0.13
Wasasa	0.80	4.90	16.33	6.00	0.17
Jos	0.75	4.30	17.44	6.00	0.13
Bauchi	0.40	4.50	8.89	9.00	0.11
Biu	2.60	3.90	66.67	9.50	0.13

Fractional Recovery (FR)

FR = Klnt + C where FR = Fractional recovery.
Klnt = Natural log of time of inoculation.
C = Fractional recovery at one day.

It has been reported that as Fe and Mn increase in the soil, its capacity to fix added P increase soil pH % clay and % organic matter also influence the ability of soils to fix P.

Since these factors O.M., Fe, Mn pH % clay vary in these soils recommended fertilizer P should also vary.

For example, if two soils have the following characteristics

	% Clay	Soil pH	Soil P	FR
KANO	9	6.20	4	0.20
POTISKUM	8	5.90	4	0.25

The amount of P required to increase P from 4 ppm to 10 ppm, which is regarded as P critical level, will differ.

Settlement of nomadic cattle rearers

Nomadic cattle rearers move from place to place in search of fresh grasses and water for their herd. At the onset of the dry season dry grasses are set on fire for fresh regrowth. Overgrazing of fertile areas often occur. These practices reduce soil organic matter, increase wind and water erosion and encourage desertification. To prevent damage to soil, nomadic cattle rearers should be re-settled and encouraged to practise mixed farming. Grass legume pastures having scattered trees should be developed and irrigation schemes developed where facilities are available or bore holes drilled in order to make water available to the herds.

Appropriate cropping systems

Location specific research should examine the choice crops of each zone and build cropping sequence around such crops. In a maize based cropping system, cowpea can be intercropped or relay cropped. Drought resistant crops should be grown towards the end of the raining season so that such crops would prevent wind erosion. Research should also be intensified into different methods of land clearing technique and equipments.

It should be noted that different clearing systems, tillage systems and intensity of mechanisation of various operations and soil management practices, magnitude and frequency of use of fertilizer and other soil ammendments, methods of crop residue management cropping combinations and sequence, and duration of various kinds of fallow present problems of soil structural modification, erosion hazards nutrient availability, efficiency and toxicity problems which in turn affect soil fertility status and overall productivity.

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35 Adaptation of Water Management Practices to Rainfed Agriculture on Alfisols in the Sahel

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Abstract The alfisols of the Sahel of West Africa are described in reference to soil and water management. Soil surface crusting which accompanies storm events is characterized and management techniques are evaluated together with the impact of mulch and termite activity. Implementation of in-place small scale water harvesting techniques are described using tied-ridges and microcatchment basins for soil-water management on alfisols. Field data from sorghum and millet verify the benefits of in-place water harvesting methods. Supplemental irrigation is introduced and proposed for use in the Sahel to increase and stabilize yields, to offset erratic rainfall, and to reduce the risk of crop failure. Three methods of irrigation are presented for use in the Sahel: surface, sprinkler, and drip/trickle.

Introduction

With population growth, shortages of food and other agricultural products will increase substantially if the level of technological output continues at its present rate in the African nations of the Sahel. Advances in rainfed production methods which are technically and economically feasible must be continued; but, an increased investment in the benefits of water harvesting and small scale supplemental irrigation must be made as a first step towards food security in the future.

These advances and investments in water management practices will have to be balanced against development of improved marketing and support facilities for rainfed agriculture. Development should be targeted toward small scale farming systems that diminish non-technical constraints which produce and dispose of surplus within each country's existing infrastructure.

The objectives of this paper are to delineate factors which restrict soil-surface management on alfisols; to describe in-place water harvesting techniques which are verified by sorghum and millet yields and plant characteristics; and, to develop the potential use of supplemental irrigation for rainfed agriculture with linkages to production agronomy within small scale farming systems.

Environment of the Sahel

The Sahel of West Africa is characterized by its two season climate: a dry season that lasts roughly from October to May followed by 4 to 6 months of rain. The rainfall is highly erratic and varies from 200 mm in the north to 1200 mm in the south. The storms are convectional in nature and seasonally balanced by the high pressure ridges of the Sahara Desert and the lows off the Bight of Benin. Air temperatures tend to be moderate, averaging nearly 30°C with maximums of 44°C during the dry season of April and minimums of 3°C (no frost) during the winter season of January.

Highly variable climatic data at the main weather stations within the Sahel has a maximum duration of about 65 years. For example, in Ouagadougou, Burkina Faso, where the 65 year mean annual rainfall of 860 mm can be compared to 762 mm for the 14 year mean annual rainfall at the Kamboinse research center only 14 km to the north. Periods of drought put a severe stress on plants and if the soil surface has been puddled or crusted from previous rainfall, the opportunity for infiltration with oncoming rains is limited.

West Africa is made up of ancient crystalline rocks that have been above sea level long enough to be worn to plateau surfaces of highly indurated sediments of pre-Cambrium age which form the substrate (FAO-Unesco, 1977). West Africa has no true fold mountains like the Alps of Europe. The alfisols south of the Sahara Desert consist mainly of ustalfs. On the upper parts of the slopes, these soils have a loamy sand to sandy loam surface followed by a clayey horizon that contains a few iron nodules (ferric luvisols). Further down the slopes the surface soils tend to loams with restricted internal drainage. These soils have poor structural properties because of low clay and organic matter contents in the surface layers. However, iron concretions increase in abundance with depth which progressively impedes the internal drainage (Sanchez, 1976).

Factors of soil-surface management on alfisols

Alfisols of the Sahel have the general characteristics as presented in Table 1 with water relationships summarized in Table 2. Additional information on these soil types has been presented by Roose (1981). In many of the alfisols, the pH at the soil surface (0-10 cm depth) varies from 4.0 to 8.0; however, most soil surface and plow layers are predominantly acidic. As the soil depth increases, the bulk density increases which is caused by either compaction or by the ferralitic gravelly materials that are formed at the lower soil depths. Alfisols on the upper portions of the colluvium have clay contents which increase with depth. Two factors which may govern this effect are:

i. the downward movement of finer particles with water percolation; and,
ii. the upward movement of clay particles caused by the action of termites and the eventual loss of these fine particles by erosion.

As the clay content and the bulk density increase with depth, the rate of percolation is restricted. These relations can be put in perspective by the *in situ* lysimeter data of Charreau (1972) for an alfisol in Burkina Faso which shows runoff of as much as 32% of the annual rainfall for a cultivated well-tilled soil and as high as 60% for a bare soil. He notes that annually as much as 8 tons/ha of soil can be lost from a cultivated field and 20 tons/ha from a bare field attributable to the forces of soil-water erosion.

As clays continue to wash out or erode from surface soils, textural changes occur, wind and water erosion hazards increase, and erosion losses

Table 1 Average characteristics of loam and sandy loam soils showing percent particle size distribution, bulk densities, gm/cm^3, hydraulic conductivity, K, cm/h, pH, percent base saturation (%BS), and cation exchange capacity (CEC), me/100gm, of soil by depth (cm).

Soil Depth	Particle Size Distribution sand	silt	clay	Bulk density	K	pH	%BS	CEC
Loam								
0 – 10	52.3	32.1	15.6	1.25	4.8	6.2	61	4.82
10 – 20	61.4	17.4	21.2	1.43	3.2	6.0	54	5.74
20 – 50	49.7	21.6	28.7	1.69	3.5	5.7	69	5.34
50 – 100	50.1	20.4	29.5	1.84	3.0	5.4	74	4.46
Sandy loam								
0 – 10	68.6	12.2	19.2	1.33	8.7	6.8	52	3.37
10 – 20	62.2	15.1	22.7	1.52	4.5	5.9	76	4.41
20 – 50	54.1	17.8	28.1	1.68	3.1	5.6	73	4.04
50 – 100	48.4	22.1	29.5	1.78	2.3	5.9	74	3.96

Table 2 Soil-water characteristics (% dry weight basis) and infiltration rates for alfisols of the Sahel.

Soil	Saturation %	Field Capacity %	Wilting Point %	Infiltration Rate cm/hr
Loam	39	15	7	1.8
Sandy Loam	30	8	4	2.2

of the sandy types of surface soils help to render them unproductive. The estimates of surface runoff from any given area in the Sahel vary from 40% to 80% of annual rainfall with the former value being applied early in the rainy season and the latter value towards the end. Effectively, farmers are losing more than half of the rainall that reaches their plot of earth.

Soil Surface Crusting

Soil surface crusting is a major concern to soil-water conservation and is a function of the impact and intensity of raindrops, duration of rainfall, soil surface condition, soil surface texture, quantity of organic matter, soil and air temperature, wind movement, and concentration of iron and aluminum compounds. Interacting combinations of these factors in the soil matrix determines the extent of a compacted crust which can form at the surface. The alfisols of West Africa have all the necessary ingredients available to ensure crusting at the soil surface. The specific conditions which lead to soil surface crusting in alfisols are one or more of the following:

1. raindrop impact;
2. chemical relations for crusting,
   a. rapid pH changes ranging from acid to basic soil with neutral rain,

b. iron and aluminum bonding,
c. processes accelerated by high soil surface temperatures,
d. rapid dehydration following rainfall; and,

3. clay and organic matter content.

Raindrop impact: During a typical convective storm in the Sahel, wind driven raindrops striking a dry bare soil surface under the force of a squall or storm front can have an intensity of about 1000 mm/hr for a short period of time where raindrops are driven downward at a velocity of about 60 cm/sec. This force is absorbed by the soil surface and these falling raindrops breakdown and disperse soil aggregates. Clay and organic particles become totally disassociated by the energy and dispersive capacity of these falling raindrops.

With the high intensity of raindrops and soil surfaces of gentle relief, water has a tendency to stack creating a microponding effect. When the soil surface is wet and microponded, the force of the raindrops striking the surface causes a thin water film to become puddled or muddy. Dispersed clay and organic particles entrained in the water film move downward by the actions of gravity and infiltration. They clog the soil pores immediately at or near the surface and form a thin dense layer. This thin soil layer is made of oriented clay and organic particles with few isolated air pores (Evans and Boul, 1968).

Reduction in the infiltration rate by the clogging of soil pores is estimated to be greater than 2000 times the initial infiltration rate (McIntyre, 1958; Wischmeier and Smith, 1958). If the soil surface is not managed appropriately; the sealing process continues with each rainfall event, increasing the depth of surface crusting and compaction which further reduces infiltration and increases runoff.

If both size of raindrops and their impacted velocity are maximized for enough time, they will release fine clay and organic particles from deeper soil depths which add to crusting at the surface. This crusting process could be limited with the possibility of runoff which would remove the fine clay particles from the surface. If the force of the driving rain persists without surface runoff, puddling would continue and the depth of surface crust could increase with time. However, if surface erosion is negligible then the depth of crust formation should be predictable. With each additional rainfall, the process would contribute to increases in the compacted layer to greater and greater depths.

Chemical relations for crusting: When a raindrop strikes a dry soil surface with an acid reaction (pH = 4.2 for example) and the water from the raindrop has a neutral reaction (pH = 7.0), the newly developed thin water film with entrained fine clay and organic particles would exhibit a rapid rise in pH (4.2 to 7.0). This chemical reaction creates an immediate increase in the number of negative charges associated with an increase in the cation exchange capacity, CEC (de Villiers and Jackson, 1967). If sufficient amounts of iron and aluminum compounds are available, they would be deposited within the interlayers of the clay minerals bonding the particles together with a concurrent raising of the CEC in the thin soil layer. With a rapid rise in pH, and the accompanying increase in net charge per particle, there is an increase in the bulk density and physical strength of the thin compact soil layer, i.e., crust formation occurs.

Crust formation is expedited by high soil surface temperatures and the additional heat of wetting when raindrops strike a dry soil surface. The high temperature increases the activity of the ions and hastens ion exchange reactions. During the rainy season, soil surface temperatures as high as 65°C (Chase, 1983) have been measured on sandy soils of the Sahel. When rainfall occurs on soils at this high temperature, the water is heated and rapid chemical reactions are facilitated.

As the soil wets, the thermal conductivity of sandy soils increase to as much as 0.005 cal/cm/sec/°C resulting in a continuous passage of heat from the deeper soil to the wetted soil surface during rainfall which would accelerate chemical reactions and processes of crust formation. When rainfall ceases, the sun dries out the surface crust rapidly and the charges on the fine particulates become fixed by cations, i.e., the thin compact soil layer sets up like cement. The interactions of the crust formation process creates an environment whereby the thin surface layer becomes dense and inflexible to all but the strongest forces.

The addition of wind driven rain striking a soil rapidly increases the pH of the microponded acid soil surface which releases negative charges to affect a sizable pH-dependent CEC. These negative charges require a high specific surface on a mineral with positive edges of hydroxy aluminum which have a net negative permanent charge and could be satisfied with cations in the soil solution, e.g., iron and aluminum compounds. The adsorption of colloidal ferric hydroxide becomes irreversible upon dehydration and is an important factor to produce stable aggregates in certain soils, especially alfisols. When ferric hydroxide is in a microponded solution, it acts as a flocculating agent and upon rapid dehydration becomes more gelatinous and exerts a cementation action which would bind the flocculated particles together (Arca and Weed, 1966). When hydrated colloidal ferric hydroxide adheres to clay minerals it cannot be removed mechanically, only chemically. This cementation process works on both iron and aluminum compounds bonding to form stable aggregates in soils of acid reaction.

Clay and organic matter content: Organic matter is conducive to the formation of large stable aggregates (Baver, 1956). If surface soils contain low amounts of clay; then, the organic matter content (however small) contributes heavily to stabilize soil aggregates. On alfisols, the presence of only small quantities of colloidal humus and clay particles are enough to aggregate soil particles during crust formation with rapid dehydration. The effects of organic matter on crust formation are best described by the importance of sesquioxide-humus reactions in developing stable aggregates. Humic acid is absorbed relative to ferric oxide gels which results in production of organic mineral compounds by interaction of humic acids and free sesquioxides.

Although crust formation is detrimental to infiltration, this characteristic of alfisols could be important in the construction of catchment areas for water harvesting. When the soil surface forms a crust, this could have an immediate cost benefit in the design and construction of water harvesting system. When runoff is maximized the technique collects water for distribution onto designated areas to supply an adequate amount of water for crop growth. For example, the soil surface of a rainfall catchment area could be formed into large furrows or ridges which would direct surface water into channels. The ridged soil surface would be compacted and runoff collected for storage in a pond or it could be immediately redistributed onto cultivated areas. When a catchment surface is properly compacted, designed and constructed, runoff from light rain showers of 3 to 4 mm can be collected for future use.

In-place water harvesting techniques

Minor changes in rainfall distribution patterns in the Sahel can cause either increased yields or depressed yields. This sensitivity to the stochastic nature of climate does not permit farmers total control over agricultural production in rainfed regions but instills an esoteric risk parameter which is itself an illusive stochastic variable (Perrier, 1984). Water harvesting does not change the nature of weather but weather's impact on dryland agriculture is less devastating using these techniques (Perrier, 1986). Collected runoff water can be stored in-place on terraced or tied-ridged agricultural plots, or stored in soils, behind dams, and in wadis. Selection of an in-place water harvesting system depends on evaluation of the soil and rainfall quantity, distribution, and intensity, as well as, site topography and labor supply.

Water harvesting techniques of capturing water and holding it in-place serves as a simple technique to minimize runoff. The concept of zero-runoff implies that rainfall remains on the soil surface until it infiltrates into the soil or is collected for future plant use. Techniques which have been used in most rainfed agricultural regions for retaining rainfall in place are called tied-ridges (Hudson, 19781) or with slight modifications are called micro-catchment basins. Figure 1 shows that tied-ridges cover the soil surface with closely spaced ridges in two directions at right angles, so that the ground is formed into a series of rectangular depressions.

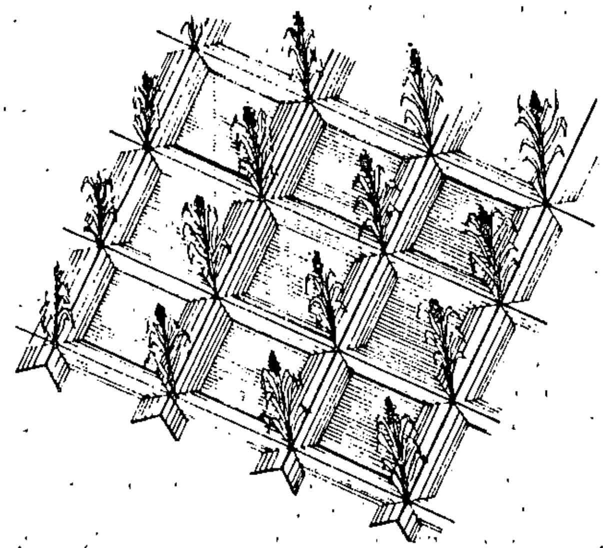

Figure 1 Schematic view of tied ridges in a field layout.

Ridges and depressions increase the potential for water storage on the surface and provide for runoff trapping which increases infiltration and water storage in the soil profile (Boa, 1966). If the infiltration rate of the soil is adequate to replenish the soil moisture in the root zone during rainfall or within a day after rainfall then whether surface water is captured or permitted to runoff is immaterial. Tied-ridges can be an effective system but they help to produce increased yields *only* when surface runoff occurs at a greater rate than infiltration.

Many mechanical devices are available for both animal traction and tractor power especially designed to make tied-ridges in a single operation.

However, ridges may be formed by tractor or oxen with ridgers (listers) with ties constructed by hand. Usually, ridges are formed parallel to one another, planted on the tops, and tied or dammed in the furrows. Sometimes the tieing, damming, or blocking of the ridges are made at the same height as the ridge. Hudson (1971) gives a word of caution about this construction technique, if the soil becomes saturated with the depressions filling up and then overflowing, the ties or dams may break. On sloping ground, once one ridge breaks it releases a small flood which can burst the next ridge releasing more stored water and so on down the slope. To correct this situation, ridges should be constructed on grade or contour with the ties lower than the ridge.

Tied-ridges can be constructed as micro-catchment basins. Figure 2 shows deep basins of 30 cm which should capture all the water that falls or runs into them. For example, if the rainfall probability curve for a 25-year storm is 80 mm, then a deep basin of 300 mm would capture all rainfall and hold it in storage for eventual infiltration. The differences of the two systems, tied-ridges and micro-catchment basins, involve rainfall distribution and intensity, soil type, and slope as well as maintenance and labor requirements.

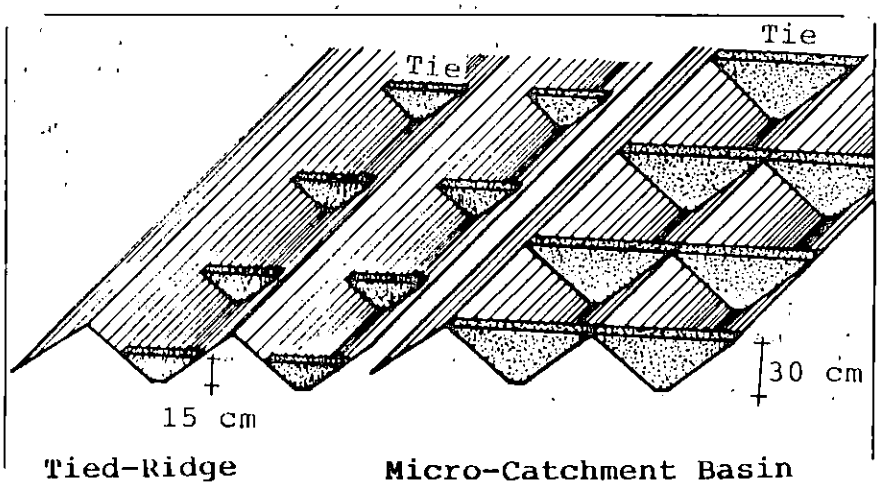

Figure 2 Schematic diagram showing the cross sections of tied-ridges and micro-catchment basins.

In some areas the ridges are left in-place throughout the dry season to catch early rains, minimize runoff, and permit early cultivation of the soil. Under no-till practices, the tied-ridges remain from two to three years with minor maintenance; however, these systems are hand seeded and hand weeded.

During rainfall, the addition of plant residue improves infiltration on these alfisols by two distinct methods: one, mulch absorbs the impact of wind driven rain and no puddling or muddy water remains in the basin; and the other, mulch increases termite and biological activity.

Termites begin consuming mulch at a slow rate immediately after placement in the catchment basin; nonetheless, by the end of August a small amount of the debris remains. Termites consume only the rice, sorghum and millet dry mulch material and do not attack the growing sorghum and millet plants. Surface water, collected from rainfall, enters the soil profile through micro-holes or pores made by the termites. Runoff from tied-ridges does not occur when protected by the implanted mulch with termite activity. During the active phase of termites, large amounts of clay materials are transported from deeper horizons to the sandy surface which should, in time, benefit the upper layers of the alfisols. However, if not protected these clay materials can erode down the slope.

Biological decomposition starts immediately after rainfall on mulch. As these materials are decomposed and digested by soil organisms using available nitrogen, their by-products become a part of the underlying soil horizons by infiltration. Biological activity increases micro-pores in the soil profile providing multiple pathways for water entry into the root zone.

Verification of In-place Water Harvesting Techniques with Yield Data

At the Kamboinsé Agricultural Experiment Station, Burkina Faso, the alfisols for sorghum and millet production are ferralitic soils of reddish color with low base saturation and poor internal drainage. These soils show deficiencies in nitrogen and phosphorus and are subject to considerable micro-variation often linked to their position in the toposequence (ICRISAT, 1980). Topsoils are shallow and the surface, if not properly managed, readily crusts with raindrop impact which can result in sizeable runoff.

Use of in-place water harvesting and mulch on alfisols of the Sahel reduces the amount of disease infestation as well as the amount of weeding necessary. By plowing before planting, the yield of sorghum variety E 35-1 increased by 236% over traditional planting methods, and by using in-place water harvesting (tied-ridges with mulch) the yield increased by 493%. When no plowing was done, E 35-1 was severely affected by loss of seedlings which resulted in significant yield reduction; however, seedling loss was circumvented by using mulch. Tied-ridge treatments gave highest yields for both sorghum and millet. The exotic varieties provided a much greater yield response for an equivalent increase in work effort; whereas, more work did not necessarily mean a greater yield response for the local variety. The local variety is adapted to environmental conditions and the low level of agronomic inputs found in the Sahel.

Sorghum production

Sorghum research investigated three varieties of sorghum whose characteristics are given in Table 3. Data given in Table 4 (Perrier, 1984), showed the effects of soil surface treatments, traditional flat planting and in-place water harvesting (tied-ridges), with and without plowing, on yield and growth characteristics of two varieties of sorghum. The ridges were tied or dammed immediately after germination followed by the addition of rice straw mulch (6 tons/ha) in the catchment basin. Tied-ridges required maintenance on ties twice during the growing season because of raindrop impact with severe storms.

Sorghum yield more than doubled with addition of mulch. Tied-ridges were the best soil surface treatment for the two varieties. No significant differences in yield were found between open and tied-ridges with mulch. Interaction between plowing treatment and variety showed yield for E 35-1 increased with surface management at a greater rate than yield of the local variety for similar treatments. When traditional flat planting was cultivated after each rain, a slight but not significant increase in yield occurred when compared with traditional flat planting without cultivation. During mid-season drought, plants on all treatments using mulch showed less stress, as observed by color and curling of leaves, than those in other treatments.

Table 3 Characteristics of sorghum varieties (SORGHUM *bicolor*).

Category	E 35-1	Local	S-29
Origin	Ethiopia	Burkina Faso	Burkina Faso
Soils	Adapted to deep soils (75-100cm)	Moderate to deep soils (40-100cm)	Moderate to deep soils (40-100cm)
Rainfall Zone of Adaptation	650mm to 850mm	650mm to 850mm	650mm to 850mm
Growth Cycle	125 days	130 days	127 days
Photosensitivity	Partial	Total	Total
Number of Days to 50% Flowering	80 days	82 days	80 days
Mean Height	2 metres	4 metres	4 metres
Type of Panicle	Compact	Loose (Guinea)	Loose (Guinea)
Grains	Large hard endosperms Pearly white	Small endosperms Chalky; Speckled white	Medium endosperms Chalky; Speckled white
Disease Resistance	Leaf; Parasite; not striga	Susceptible; not striga	Susceptible; not striga
Seeding Date	After 15 June	After 1 June	After 1 June
Planting Density (Plants/ha)	60,000	75,000	80,000
Potential Yield	4.0 tons/ha	2.2 tons/ha	3.0 tons/ha
Field Preparation	Plowing, lacks seedling establishment	With or without plowing	With or without plowing

Table 5 shows the effect of size of water catchment area on sorghum yield for each variety. Yields of the 0.50 m^2 water catchment area was nearly double that of the 1.50 m^2 basin. E 35-1 responded to size of catchment area at a greater rate than did the local variety. The 0.50 m^2 catchment area was best and significantly increased yield for both varieties.

Measurements of plant node diameter, distance between nodes, leaf length and leaf width for sorghum are shown in Table 6. Data show a significant effect for soil surface treatment (traditional flat planting and tied-ridges with 15 tons/ha of sorghum mulch) and variety. The average percent increase in yield from traditional flat plantings to tied-ridge with mulch treatments for these varieties was 346% when the field was plowed and only 199% increase when not plowed. Total plant dry matter showed similar comparisons from traditional flat planting to tied-ridges with mulch for these varieties with an average of 171% increase with plowing and 137% increase without plowing. For evaluation, treatment differences were put at the extremes as the best consistent soil surface treatment was tied-ridges with mulch and the poorest was traditional flat planting. Plants consistently increased in volume and length at the highest level of water management.

Table 4 Effect of soil surface treatment, cultivation, and plant variety on yield of grain (tons/ha).

		Soil Surface Treatment (c)							
		Traditional			In-place Water Harvesting				
Plow Treatment	Sorghum Variety	Flat	Flat With Mulch	Flat Cult	Ridges Open	Ridges Open/ Mulch	Ridges Tied	Ridges Tied/ Mulch	Plow Versus Variety Means (b)
Plow	E 35-1	1.57	3.60	2.02	2.41	3.10	2.20	3.29	2.60
	Local	1.10	2.66	1.39	1.63	2.32	2.32	2.83	2.03
No Plow	E 35-1	0.67	2.59	1.45	0.50	2.20	1.86	2.93	1.76
	Local	0.91	2.80	1.46	1.00	2.18	1.50	2.30	1.73
Means (a)		1.06	2.91	1.58	1.39	2.45	2.00	2.84	

(a) LSD, 5% = 0.54
(b) LSD, 5% = 0.18
(c) LSD, 5% among soil surface treatments for same variety = 0.77
among the same soil surface treatments for different varieties and plow treatment = 0.77

The analysis of variance showed:

1. plowing treatments – significant (F = 26.3, df = 1/56);
2. varieties – significant (F = 6.88, df = 1/56);
3. soil surface treatment – significant (F = 24.1, df = 6/56);
4. interaction between plowing treatment and variety – significant (F = 5.89, df = 1/56);
5. comparison between mulched and non-mulched plots – significant (F = 128, df = 1/23).

Table 5 Effect of catchment area (m^2) and plant variety on grain yield (tons/ha).

Sorghum Variety	Size of Catchment Area (c) 0.50	0.75	1.00	1.25	1.50	Variety Means (b)
E 35-1	5.17	4.33	4.11	3.56	2.79	4.02
Local	3.00	2.76	2.45	2.24	1.90	2.49
Means (a)	4.08	3.55	3.28	2.90	2.35	

(a) LSD, 5% = 0.28
(b) LSD, 5% = 0.11
(c) LSD, 5% among size of catchment area for same variety = 0.80
among same catchment areas but for different varieties = 0.76

The analysis of variance showed:

1. varieties – significant (F = 867, df = 1/23);
2. size of catchment area – significant (F = 70.5, df = 4/99);
3. interaction of variety by size of area – significant (F = 8.2, df = 4/00).

Table 6 Relation of sorghum variety to soil surface treatment for node diameter (cm), distance between nodes (cm), leaf length (cm), and leaf width (cm).

	Plant measurements			
Sorghum Variety	Node Diameter	Distance Between nodes	Leaf Length	Leaf Width
Traditional Flat:				
Local	1.86	23.7	64.8	6.92
E 35-1	2.19	14.3	66.4	8.52
S-29	1.89	21.7	59.9	6.61
Tied-ridge with mulch:				
Local	2.04	27.9	69.4	7.42
E 35-1	2.49	15.4	69.3	9.53
S-29	2.15	24.9	66.2	6.86

After a rain of at least 1 mm, water may pond in tied-ridge basins and remain for 2 to 3 days making the environment extremely poor for seedling development but easier to control weeds. When mulch is used, the work of weeding is further reduced without the resultant ponding and puddling associated with tied-ridges without mulch. Mulching shades the soil surface of the catchment basin which, in turn, creates a poor environment for weeds.

Millet production

The plant characteristics of three varieties of millet used in these studies are shown in Table 7. Data show the effects of soil surface treatments, traditional flat planting and in-place water harvesting (tied-ridges) on yield, plant characteristics, and disease infestation on two varieties (Table 8). The ridges were tied immediately after germination and rice straw mulch (6 tons/ha) was applied in the catchment basin. The sandy loam soil was easy to manage when making tied-ridges: however, these soils tended to "melt" under severe wind driven rains and required maintenance three times during the growing season.

The total number of heads/plot of millet for soil surface treatment and plant variety is given in Figure 3. The analysis of variance showed:

1. varieties – significant ($F = 44.6$, df = 1/2);
2. soil surface treatments – significant ($F = 122.84$, df = 3/12); and,
3. interaction – significant ($F = 18.5$, df = 3/12).

Traditional flat plantings and ridges (not tied) were not significantly different for both varieties. The interaction resulted from more heads with increased soil-water management for Ex-bornu than for the local variety.

Additional research demonstrated the effect of basin area on yields of three varieties of millet (Ex-bornu, Souna-3, and a local variety). Yields are presented in Table 8 for size of catchment area and plant variety. Millet yields were affected by downy mildew especially in the 0.50 m^2 and 0.75 m^2 catchment basins with the local variety being most severely affected

Table 7 Characteristics of millet varieties (PENNISETUM *Typhoides*).

Category	Souna-3	Ex-bornu	Local
Origin	Mali	Nigeria	Burkina Faso
Soils	Light Sands (30-40cm)	Sandy (30-40cm)	Sandy (30-40cm)
Rainfall zone of adaptation	500-800mm	600-900mm	650-800mm
Growth cycle	75 days	75 days	120 days
Photosensitivity	None (Gero)	None (Gero)	Total (Maiwa)
Number of days to 50% flowering	55 days	55 days	80 days
Tillering	Many	Many	Many
Mean height	2 metres	1.8 metres	2.9 metres
Length of head	45cm	30cm	22cm
Grains	Large Slightly hard	Medium size	Little; Hard
Disease resistance	Good	Good	Poor
Seeding date	20 June to 10 July	20 June to 10 July	After 1 June
Planting density (plants/ha)	65,000	65,000	70,000
Potential yield	3.0 tons/ha	2.5 tons/ha	1.2 tons/ha
Field preparation	With or without plowing	With or without plowing	With or without plowing

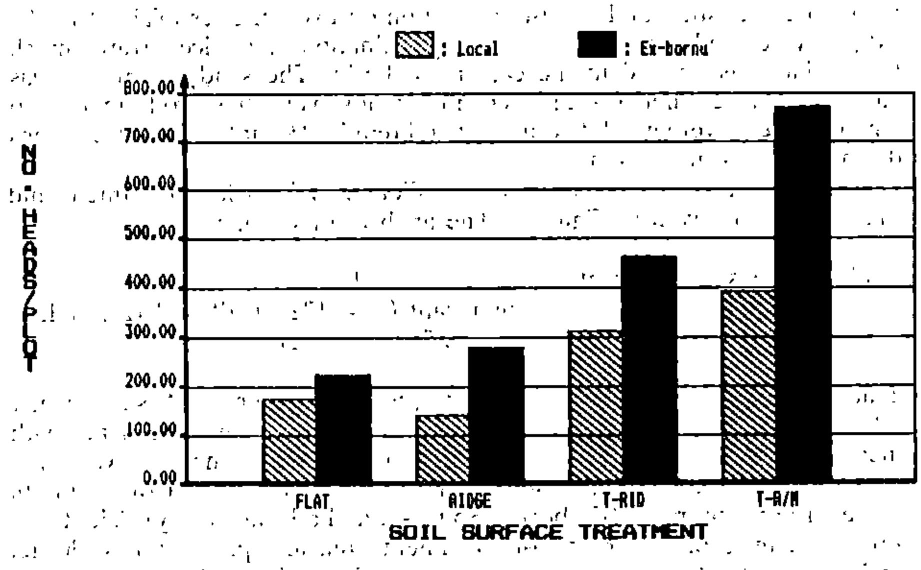

Figure 3 Effect of soil surface treatment and plant variety on total number of heads/plot.

Table 8 Effect of catchment area (m^2) and plant variety on grain yield (tons/ha).

Millet Variety	Size of Catchment Area (c) 0.50	0.75	1.00	1.25	1.50	Variety Means (b)
Local	1.00	1.12	1.14	1.02	1.07	1.07
Ex-bornu	2.11	2.33	2.41	1.97	2.14	2.19
Souna-3	2.23	2.18	2.59	2.39	2.33	2.35
Means (a)	1.79	1.88	208	1.79	1.84	

(a) LSD, 5% = 0.19
(b) LSD, 5% = 0.14
(c) LSD, 5% among size of catchment area for same variety = 0.40;
among same size of catchment area for different variety = 0.64.

The analysis of variance showed:

1. varieties – significant (F = 165, df = 2/18);
2. size of catchment area – significant (F = 7.12, df = 4/162);
3. interaction between varieties and catchment area size – significant (F = 2.19, df = 8/162).

throughout all treatments. Data show that a catchment area of 1.00 m^2 is best for millet production. Souna-3 produced significantly more grain than Ex-bornu and both varieties produced significantly more grain than the local.

Table 9 shows that Souna-3 had the highest harvest index and was the most efficient grain producer with less energy used to produce dry matter. Trends in seed weight/1000 grains was towards heavier weights as size of catchment area increased; furthermore, weight/1000 grains was significantly different for each variety. Total plant height, taken at 50% flowering, followed a similar pattern as grain yield with the 1.00 m^2 area producing the tallest plants. The taller local variety produced significantly more dry matter than either Ex-bornu or Souna-3. No significant difference was found between total dry matter production of Ex-bornu and Souna-3.

Figure 4 shows that smut, ergot, and downy mildew infected Ex-bornu more than the local variety. All three disease infestations were significantly affected by soil surface treatment. Tied-ridges were significantly less infested than traditional flat or open ridges with the addition of mulch being least affected for variety and soil surface treatment.

Table 9 Variety of millet to harvest index (%), seed weight/1000 grains (gm), total plant height (cm), and total dry matter (tons/ha).

Millet Variety	Harvest index	Seed weight/ 1000 grains	Total plant height	Total dry matter
Local	20.3	9.82	332	5.26
Ex-bornu	51.5	11.14	255	4.25
Souna-3	65.1	10.72	256	3.61

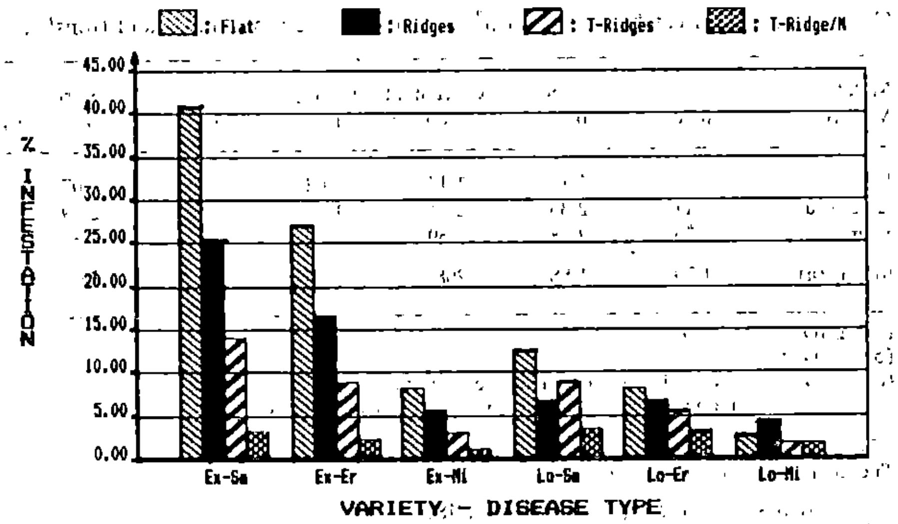

Figure 4 Effect of soil surface treatment on diseases for Ex-bornu (Ex) and Local (Lo) and smut (Sm), ergot (Er), and downey mildew (Mi).

Potential Use of Supplemental Irrigation for Rainfed Agriculture

Alfisols in the Sahel occur under unfavorable climatic conditions of the ustic environment. Even though physical and chemical characteristics of these soils are not particularly favorable, the interacting combination of soil-water management, fertilization, and use of sorghum and millet varieties which respond well to increased level of managemennt can bring about yield stability. Water is the limiting resource in the Sahel and improvement of water management promotes higher and more stable yields which directly benefits the rural community.

Yields of sorghum and millet varieties used in the verification studies were sensitive to variations in climate. Minor changes in rainfall distribution patterns throughout the growing season increased or reduced yields. This sensitivity to the stochastic nature of climate precludes control over rainfall; and as a consequence, the production variables of yield and plant dry matter remain at high risk within the traditional farming system. The erratic distribution of rainfall which manifests itself with extended droughts and rain storms of high intensity is undeniably disastrous to the region.

The goal of water management is to develop technical alternatives to stabilize yield and improve productivity of basic food crops in rainfed areas of the Sahel. The potential for increasing agricultural production is indeed high and can be exploited by administration of:

a. water conservation technology;
b. in-place water harvesting farming; and,
c. supplemental irrigation.

Water conservation technology

Agronomists, engineers and economists proceed from a consideration of natural factors, including population demands, to view water conservation as yet another means for adapting to a specific environment. Any method which will increase the amount of rainfall infiltrating into the soil will increase productivity in the Sahel. Moisture conservation technology is concerned with reducing runoff to negligible amounts, retarding direct evaporation from the soil surface, limiting transpiration by weeds, and using the bulk of the rainfall for crop transpiration or water storage within the soil profile for later use by the crop. Optimal water storage in soil requires that an adequate amount of rainfall infiltrate to the depth of roots with the remainder of the water stored in a catchment area of aquifer recharge for later distribution and use.

In-place water harvesting farming

Aside from techniques of runoff interception by sloping or drainage terraces and contour furrows for intercepting runoff and rainfall, in-place water harvesting and mulching collect and store water as well as reduce evaporative losses. The success of farming under rainfed conditions depends not only on the effective collection of runoff (water harvesting), but also upon efficient use of water by agricultural crops. Uncertainties of rainfall-runoff events are difficult to reconcile with crop water requirements but the use of tied-ridges or micro-catchment basins reduces the uncertainty of risk. Farmers in traditional rainfed agricultural areas have little, if any, risk-bearing capacity; therefore, it becomes crucial for them to choose a crop and management system that can make the best use of water collection and storage (Carpenter, 1980). The use of supplemental irrigation will alleviate the climatic risk factors by increasing choices for soil and crop management which will stabilize crop-water requirements and, therefore, yields.

Supplemental irrigation

The potential for increasing food production in rainfed areas may be high but the risk involved with the amount, frequency, and duration of rainfall requires implementation of supplemental irrigation to stabilize production. In an area where a crop can be grown by natural rainfall alone; but additional water produces improved yields, irrigation is termed supplemental. Agricultural lands suitable for supplemental irrigation must have four basic features: irrigable terrain; potentially fertile soils; a climate in which a rainfed crop can thrive; and, a source of water of consistent quality.

In addition to securing higher and more reliable yields, supplemental irrigation can also provide conditions suitable for using high agronomic inputs, i.e., high yielding varieties, more fertilizer, and more intensive cropping. Supplemental irrigation's impact on rainfed farming demonstrates an economic increase in agricultural productivity that can be achieved by the avoidance and management of risk. It represents an improvement in technique on traditional farming practices and whether to irrigate or not is decided purely on the estimated profitability of doing so.

Data show that supplemental irrigation is associated with more sophisticated methods of farming and marketing and represents an improvement in technique on traditional farm practices (Perrier and Salkini, 1987). It permits higher yields by increasing the total volume of water applied as well as timing of irrigations at critical stages of growth and periods of drought.

Demonstrations of supplemental irrigation efficiency at the farm level is an attempt to bridge the scientist/farmer gap with an equitable distribution of technology. Yield/gap ratios represent the differences in yields achieved under intensive management by researchers at experimental stations to yields achieved by farmers using traditional practices. When the ratios are large then technology transfer from the research center to the farmer has not occurred; that is, the agricultural management program for increasing crop production developed at the research center has *not* been accepted by farmers.

A crop intensity of 100% implies that land area is being used more than once throughout a growing season, e.g., one crop is planted in the rainy season and another in the dry season with supplemental irrigation. Multiple cropping during one growing season can increase the cropping intensity to more than 100%. Agronomic diversification results from multiple cropping of field and speciality crops which enables the farmer to distribute economic risk over a variety of crops; whereupon, fluctuations of income are diminished with the development of a market economy.

Figure 5 shows the salient characteristics of rainfed areas which have unstable yields and low cropping intensity. These, together with demographic explosion and rises in standard of living, contribute to degradation of natural resources which perpetuates low yields, inadequate food supply, and poor public health. Supplemental irrigation *does* affect social organization and brings about stratification *if* there is a scarcity of water, or *if* conditions exist that, in effect, restrict access to water or land (Downing and Gibson, 1974). The introduction of supplemental irrigation into traditional rainfed farming alleviates the farmer's dilemma through prospects of stable crop production, increased yields, surplus food supply, a cash crop program, and a market economy.

Alternative water sources such as check dams, wells, pumpback systems, and intermittent streams are useful for supplemental irrigation to reduce the risk of a poor harvest during periods of low rainfall. To ensure that time and money are not wasted, alternative methods of water supply for irrigation should be considered before installation of an irrigation system. Storage of water in small check dams, catchment ponds, or reservoirs is a common technique to impound storm runoff for eventual use by supplemental irrigation. Small dams constructed across flowing and intermittent streams as well as wadis (gullies) create storage behind the dam walls. In many instances, these dams are handmade using rock and concrete cores with a compacted clay-earth cover and gravelled spillway. In general, these types of reservoirs are used for supplemental irrigation to reduce risk and increase yield.

The water balance method is calculated to determine supplemental irrigation requirements under local conditions to ensure the effective and efficient use of water. Water balance for irrigation scheduling is determined by measuring major input and output components of water movement. The equation is given as

$$R + I = ET + RO + S,$$

where:
R = rainfall on a field, mm;
I = water added by irrigation, mm;
ET = evapotranspiration, mm;
RO = runoff, mm; and,
S = soil-water storage, mm.

Simple calculations estimate the water requirements and time of irrigation for a particular crop (Doorenbos and Pruitt, 1984 and Perrier, 1986). Verification of the calculations are made by measuring soil moisture in the soil profile as a function of time.

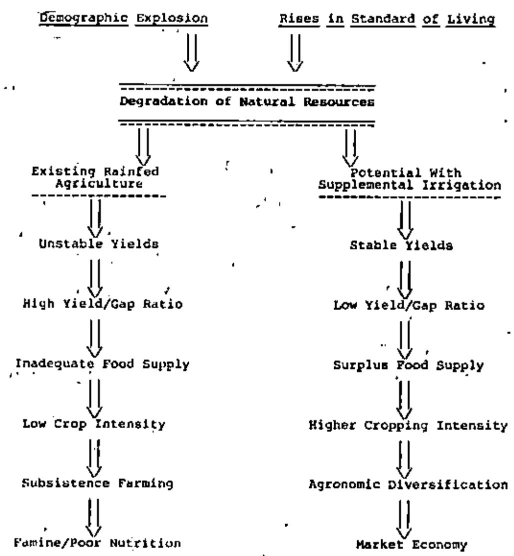

Figure 5 Impact of supplemental irrigation on agronomic productivity.

Selection of a Supplemental Irrigation Method

Selection of a supplemental irrigation method is based upon technical and economic feasibility as well as traditional values of agriculture. When considering the economics of a supplemental irrigation system, all costs and benefits should be included. If water is inexpensive and soil types and topography are adequate, surface irrigation methods are the cheapest to install and operate. The most popular method for supplemental irrigation is the field spray outlet of rotating impact sprinklers. A major argument in favor of a non-surface type of irrigation is the ease of operation which portable sprinkler systems offer: not only for scheduling and estimating volume requirements of irrigation, but also for the uniform distribution of applied water. If an irrigation system is new, then start-up difficulties are lessened with sprinkler irrigation. When water is expensive or scarce, the best choice may be drip or trickle irrigation. This method uses frequent, slow application of low pressure water to soils through mechanical devices called emitters at selected points along a water delivery line. Drip systems allow more precise control of soil moisture in the plant available moisture range than does surface or sprinkler irrigation techniques.

Surface methods

Surface irrigation includes such methods as furrow, border strip, and basin. If a surface irrigation system is properly designed and managed it is possible to achieve good uniformity of water spreading (Burt, 1985). Five factors are important for effective management of surface irrigation:

1. a large soil moisture deficit at time of irrigation ensures a more uniform infiltration;
2. application time should allow the same opportunity for infiltration at all points in the field;

3. furrow and border strips should have optimal length for infiltration to the root depth;
4. controlled runoff is necessary on sloping furrows; and,
5. good land grading is essential.

For efficient irrigation by a surface method, slopes should be uniform with no high or low spots. Ideally a surface irrigation system should apply an equal depth of water along the run or furrow; however, in practice this is impossible to achieve. Sandy soils with low water storage capacity and high percolation require frequent light irrigations which is difficult with surface methods. For clay soils, if the amount or flow of water for irrigation is low, surface irrigation is not economical. If irrigation water contains sediment or leaching for salinity control is important, then surfaace methods of irrigation are preferable.

Sprinkler methods

Sprinkler irrigation design requires selecting a pipe layout where laterals of equal length are placed uniformly along the supply line. The system should be totally portable for supplemental irrigation but positioning of main lines could affect portability and the possibility of economic expansion. The design should not place irrigation pipes in the path of mechanized equipment but should incorporate the working pattern of the laborers. The main elements of a sprinkler irrigation system are:

1. *source* of water;
2. the *main line* used to convey water from the source to the field can be a concrete canal or steel, aluminum, or plastic pipe;
3. the *sub-mains* which follow field boundaries or the center-line of field;
4. the *laterals* used to convey water to risers and sprinklers at regular intervals; and,
5. the impact *sprinkler*.

Every sprinkler system is composed of a pipe network and impact sprinklers. The rotating sprinkler has one or two inclined nozzles mounted on a body which rotates by the action of a hammer blade about a vertical axis. In operation, one jet impinges on the blade and thrusts it aside. The blade is restrained and returned by a light spring. The return is terminated by a stop on the body which rotates by impulse through a small angle. Then the cycle is repeated. The water supply should be clean for rotating sprinklers as they may clog. Filters are usually placed somewhere in the system.

Drip/trickle methods

Drip irrigation uses perforated plastic pipes which are laid along the soil surface or subsurface at the base of a plant row with water supplied from a field main. For the duration of a growing season, all plastic pipes remain in place with water supplied on demand. The emitters or outlets are designed to release a trickle or drip of water; not a jet. Spacing of emitters is selected to produce a wetted strip along the crop row or a wetted bulb of soil at each plant.

The main advantage of drip irrigation is that it provides an excellent control of water application. The soil moisture deficit can be controlled at a low level and soil aeration is maintained. Drip irrigation is highly beneficial to plant growth and improvements in yield and quality have been achieved for a wide range of crops. This method is particularly advantageous when saline water must be used for supplemental irrigation.

Unfortunately, capital costs of drip irrigation equipment can be higher than those of surface or sprinkler irrigation. The problem of nozzle blockage at the outlets has not been completely solved and requires line filtration with maintenance. This method is best used for limited water supplies, low quality irrigation water, and high valued crops.

Discussion and conclusions

Alfisols of the Sahel are characterized by clay contents and bulk densities that increase with depth and low cation exchange capacities, hydraulic conductivities, infiltration rates, and available moisture. During the rainy season, the surface of these alfisols form hard crusts which cause excessive runoff. The pH of the surface soils is acid varying from 4.0 to 6.5 and is suseptible to crust formation with raindrop impact from wind driven rains and high soil and air temperatures.

In-place small scale water harvesting techniques of tied-ridges or micro-catchment basins reduce runoff and increase yields of sorghum and millet. Addition of plant residue in the catchment basin as a mulch improves infiltration and water storage capacity of the soil increasing yields by as much as 340%.

Supplemental irrigation is an improved agronomic technique which can incorporate the advantages of water harvesting and existing water sources to reduce the risk in rainfed areas and stabilize crop production. Small scale supplemental irrigation can be used with surface, sprinkler, and drip/trickle methods with irrigations scheduled by calculations of the water balance for local conditions.

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36 Soil and water management research in the semi-arid regions of Ethiopia

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Abstract In Ethiopia, 46% of the total arable land is arid and semi-arid. In these areas, several research activities were conducted in the last one to two decades in an effort to improve and stabilize food production.

Tillage methods and mulching did not show any significant advantage in yield increase in the black clay soil at Mekele. Seed bed preparation methods increased the yield of wheat (*Triticum* species) Sorghum (*Sorghum bicolor* L. Moench), Cowpea (*Vigna unguiculata* L. Walp) and Mungbean (*Phaseolus aureneus* Roxb.) in the drought affected areas of Mekele, Quiha and Kobo. Tie-ridges were generally most efficient methods for moisture conservation. Tie-ridge spacing of 80 and 40 cm for Mekele and Quiha, respectively, were optimum for wheat production.

Soil loss assessment studies under different cover crops for Mekele are reviewed and presented. A few irrigation trials on some food crops are also discussed.

Introduction

The dryland areas of Ethiopia account for 46% of the total arable land (637,000 km^2). The semi arid regions (91-150 days of growing period) cover 40%, and arid areas (less than 90 days of growing period) cover the remaining 60% of dryland areas and contribute less than 10% of total crop production in the country.

Soil moisture is one of the most important factors limiting crop production in the semi arid regions of Ethiopia, where present crop production is largely rainfed. The major food crops are maize, sorghum, millet, tef and lowland pulses. Despite the unreliable rainfall, most of these areas are believed to be potentially productive. The climatic elements; rainfall pattern, distribution and intensity are significant and highly influence crop production. Uneven rainfall distribution, high soil temperature and high evaporation are typical characteristics (Figs. 1, 2 and 3). Drought of varying degrees of severity also occurs frequently. As a result, partial or total crop failure due to moisture stress is a common experience.

Water deficits or moisture stress can be very critical when it occurs particularly at certain growth stages of a crop (Russel, 1981). In most marginal rainfall areas of Ethiopia, crops fail to produce enough seeds as a result of late or early termination of the seasonal rainfall. However, a substantial increase in crop production has been achieved through water conservation and management. Work in the dryland areas of Australia showed that, a yield as high as 2500 kg/ha of wheat had been achieved from 50 mm of rain that occurred during the 139 days of crop growth and 142 mm of soil water conserved during the preceeding summer (Angus, et al., 1980). In Ethiopia, despite the erratic rainfall pattern and distribution, the seasonal rainfall has not been and still is not less than 200 mm for most drought affected areas (Mekele, Kobo, etc.) where crop failures were repeatedly reported. Like elsewhere, such situations could be prevented from occurring through improved agricultural practices: by manipulating the soil in such a

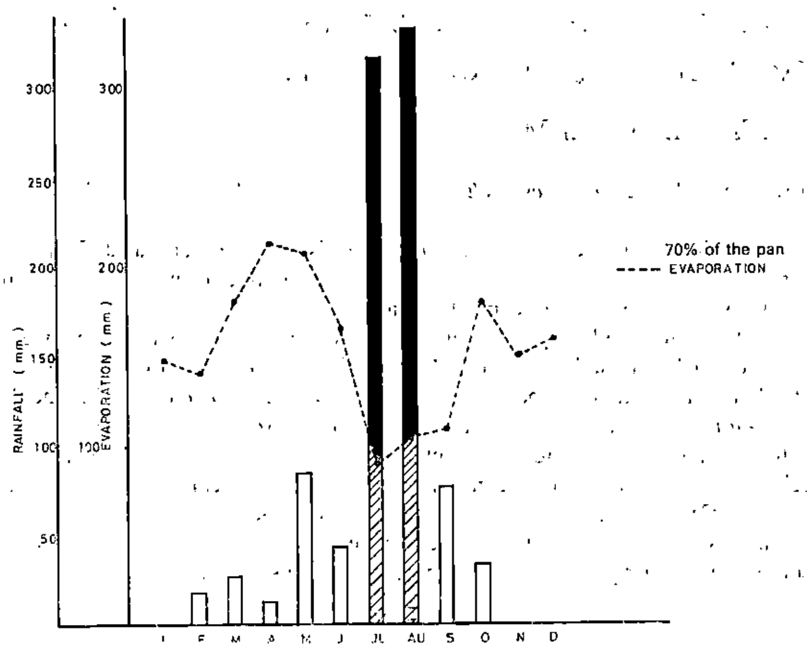

Figure 1 Rainfall and evaporation at Mekele Research Centre (1977)

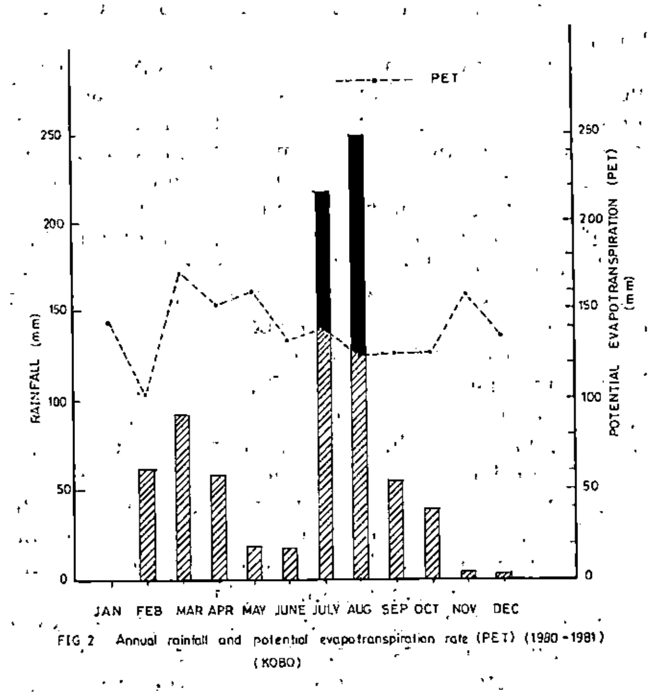

Figure 2 Annual rainfall and potential evapotranspiration rate (PET) (1980-1981) (Kobo)

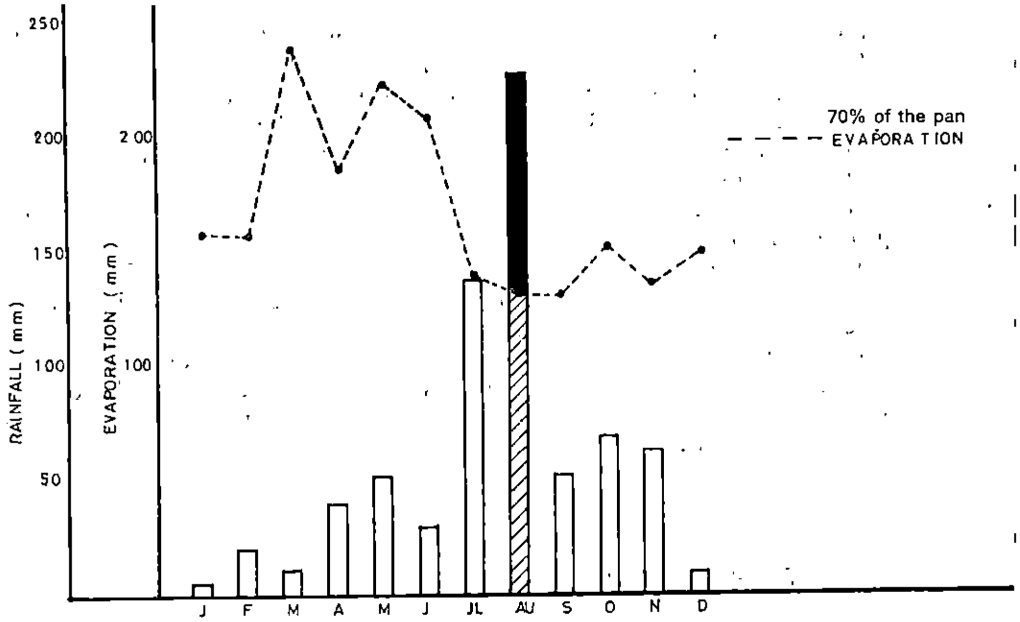

Figure 3 Rainfall and evaporation at Nazreth Research Centre (1982)

manner that moisture limitation could be partially or completely overcome.

In the last one to two decades, research activities were carried out on soil and water management practices aimed at improving and stabilizing food production in the arid and semi arid regions where soil moisture is the most limiting factor for crop production. This paper attempts to review and outline these research activities.

Results of the Research Activities

Tillage Methods and Mulching

Land preparation methods affect seedling emergence, stand establishment and consequently crop yield. In the tropics, surface mulching with crop residues have proved effective in conserving soil moisture, decreasing soil temperature and maintaining favourable soil structure through enhanced biological activity (Lal, 1974). It retains soil moisture by reducing evaporation from the soil. At the same time it has a distinct advantage of controlling erosion.

In an effort to increase moisture storage in the crop root-zone and to reduce soil erosion, tillage methods and the use of organic mulch were tested in the dryland areas of northern Ethiopia; Mekele, Quiha and Mai Mekden. Yield responses of tillage practices; local plow, moldboard, ridges (narrow and broad) and minimum tillage combined with plowing time (early and late), and mulching were compared. The result for 1974 showed that there was no statistically significant yield difference among treatments for all locations. However, at Mekele, local plow and late plowing without mulch gave slightly higher yield (1030 kg/ha) of wheat relative to broad ridge early plowing without mulch that gave the lowest yield (910 kg/ha). The low yield obtained was largely due to water-logging effect resulting from poor internal drainage. At Quiha (a substation 12 km east of Mekele) local plow and early plowing plus mulch gave 1270 kg/ha followed by mouldboard and early plowing without mulch that gave 1240 kg/ha, while the lowest yield (790 kg/ha) was observed from early plowing with narrow ridges plus mulch.

At Mai Medken (a substation 15 km north of Mekele), yield was rather low. It ranged between 880 to 1030 kg/ha. The highest yield was from late plowing plus mulch while the lowest was obtained from early plowing plus mulch. The low yield at this site was due to the relatively slopy (9%) land feature and highly degraded soil that made less moisture available for crop growth and development.

On another experiment, mulch application rate (0, 0.5, 1.5, 2.5 and 3.5 tons/ha) was studied at Mekele to examine its effect on the grain yield of wheat. The result showed no significant yield difference among mulch rates. The highest yield obtained was 1012 kg/ha from zero mulch relative to 850 kg/ha when 3.5 tons/ha of mulch was applied. Here also, the overall yield was low largely due to water logging particularly during the initial stage of crop growth.

Soil Preparation Methods

Mekele and Quiha

Trials on seed bed preparation methods (Flat, open ridges (furrows) and tie-ridges (furrows tied at intervals) were carried out at Mekele for five years, 1978-83 (Table 1). Significant yield differences were obtained among treatments with the highest yields (1800 kg/ha) observed from tied-ridges followed by open-ridges (1040 kg/ha). The lowest yield (431 kg/ha) was obtained from flat, a method commonly practiced by farmers.

Table 1 The effect of seed bed preparation on the grain yield of wheat (Mekele)

Treatment	Yield (kg/ha)					
	1978	1979	1980	1982	1983	Mean
Flat	1346	159	842	378	430	431
Tied	1830	1396	2869	1046	1683	1765
Open-ridges	986	647	1663	697	1205	1040
LSD (0.1)						674
LSD (0.5)						506

A similar study on the spacing of tie-ridges was carried out at Mekele and Quiha for the same period, 1978-83. Three spacings, 20, 40 and 80 cm, were used. A combined analysis of the results was made and significant yield differences were observed among treatments, treatment × year and treatment × location interaction (Woldamlak, 1984).

At Mekele optimum spacing of 80 cm tie-ridges gave the highest yield (2034 kg/ha) followed by 40 cm tie-ridges (1246 kg/ha) and the lowest yield (774 kg/ha) was observed from 20 cm (Table 2). At Quiha, the highest yield (1255 kg/ha) was obtained from 40 cm tie-ridges followed by 80 cm while the least (663 kg/ha) was again from 20 cm tie-ridges (Table 3).

Table 2 Effect of spacing of tie-ridges on the grain yield of wheat (Mekele)

Treatment	Yield (kg/ha)					
	1978	1979	1980	1982	1983	Mean
20 cm ridge spacing	791	539	745	673	1116	774
40 cm ridge spacing	1158	999	1745	·1067	1265	1246
80 cm ridge spacing	2149	1640	2895	1987	1500	2034

Table 3 Effect of spacing of tie ridges on the grain yield of wheat (Quiha)

Treatment	Yield (kg/ha)					
	1978	1979	1980	1982	1983	Mean
20 cm ridge spacing	394	243	706	274	16996	663
40 cm ridge spacing	549	1196	1898	822	1811	1255
80 cm ridge spacing	540	623	1572	452	1502	938
LSD (0.1)						343
LSD (0.5)						258

Kobo

At Kobo, 1500 m.a.s.l. and a typical semi arid and drought affected area in the north eastern Ethiopia, soil preparation methods and planting pattern (flat, open ridges planted in furrows, open ridges planted on the ridges, one meter tie-ridges planted in the furrows and one meter tie ridges planted on the ridges) were investigated for three consecutive years, 1980-1982, (Adjei-Twum et al., 1983a & b). The crops used were sorghum and cowpea. For sorghum, significant yield differences ($P = 0.05$) were observed during 1980 (experiment 1), and 1980 and 1982 (experiment 2) (Table 4). The yield ranged between 1303 to 2290 kg/ha (experiment 1) and 1583 to 2913 kg/ha (experiment 2). The highest yield obtained was from tie-ridges when seeds were planted on tie-ridges followed by tie-ridges when planted in the furrows on both experiments. The lowest yield was obviously from flat. The same treatments were also used for cowpea and mungbeans (Tables 5 and 6). Unlike the previous result, the highest yield (1278 kg/ha) for cowpea was from open ridges when planted in furrows followed by the ridges when planted in furrows again. The lowest yield (809 kg/ha) was from flat. A similar trend was followed by mungbeans with yield ranging betwen 460 kg/ha to 747 kg/ha.

Soil Management

Soil loss by erosion (water and wind) is a major contributor to soil degradation that reduces the actual or potential productivity of the soil to produce crops. At Mekele, soil loss rate by water erosion under different land use and agronomic practices using run-off plot experiment was reported by Getachew (1985). The soil loss varied from 2.5 tons/ha/yr (grass cover) to

Table 4 Effect of soil preparation methods and planting pattern on the grain yield of sorghum (Kobo)

Experiment No. 1.

Soil preparation methods	Yield (kg/ha)			
	1980	1981	1982	Mean
Planted on the flat	771	2057	1082	1303
Planted in the furrows of open ridges	1081	1579	3412	2024
Planted on open ridges	1251	1529	3004	1928
Planted in the furrows of tie ridges	2045	1582	2370	2240
Planted on tie ridges	2107	1871	2894	2290
LSD (0.05)	512	NS	NS	

Experiment No. 2.

Soil preparation methods	Yield (kg/ha)			
	1980	1981	1982	Mean
Planted on the flat	1315	1551	1885	1583
Planted in the furrows of open ridges	1148	2100	3018	2088
Planted on open ridges	1213	1649	3718	2193
Planted in the furrows of tie ridges	2618	1639	2741	2332
Planted on tie ridges	2918	2039	3784	2913
LSD (0.05)	512	NS	803	

Table 5 The effect of soil preparation methods and planting on the grain yield of cowpea (Kobo)

Land preparation methods	Yield (kg/ha)			
	1980	1981	1982	Mean
Planting on the flat	858	979	591	809
Planting in the furrows of open ridges	1012	1543	1280	1278
Planting on open ridges	784	1512	1178	1158
Planting in the furrows of tie ridges	1093	1401	1179	1224
Planting on tie ridges	1067	1492	1080	1213
LSD (0.05)	NS	155	252	

Table 6 The effect of soil preparation methods and planting pattern on the grain yield of Mungbean (Kobo).

Land preparation methods	Yield (kg/ha)			
	1980	1981	1982	Mean
Planted on the flat	423	467	350	460
Planted in the furrows of open ridges	586	697	645	708
Planted in open ridges	446	575	645	605
Planted in the furrows of tie ridges	648	629	749	747
Planted on tie ridges	579	596	718	695
LSD (0.05)	51	NS	168	

Table 7 Run-off and soil losses on 9.0% land slope at Mekele (1978).

Treatment	Run off		Soil loss tons/ha/yr
	m³/ha/yr	%rain	
Grass cover	257.0	9.0	2.5
Tef cover	880.0	31.0	8.8
Barley cover	1255.0	42.2	15.9
Bare fallow	1094.0	38.5	17.9

18 tons/ha/yr (bare fallow). Tef (*Eragrostis tef*) and barley (*Hodeum vulgare L.*) plots gave 9.0 and 16.0 tons/ha/yr, respectively (Table 7).

Like any other places in the Sahel, wind erosion is also a serious threat to crop production in the semi arid regions of Ethiopia. It prevails in any area where drought is frequent and temperature, evaporation and wind speed are very high (Woodruff et al., 1977). Fertile soils are blown away and gradually the land is subjected to degradation. Moreover, crops are often damaged or destroyed by abrasive effect of wind blown soil particles.

Preliminary wind erosion trial was carried out at Nazret research field. An estimated total soil loss of 124 tons/ha was recorded from April 20 to June 27, 1985. The data for November, December, January and February were 85, 50, 15 and 54 tons/ha for 17, 13, 5 and 10 recorded days, respectively. The April-June data was high because vegetation cover was minimal due to the 1984 drought. This work is now continuing.

Crop Production under Irrigation

In the ten year plan, the Ethiopian Government placed a high priority on irrigation. The unreliability of the rain and the occurrence of periodic drought and prevailing food shortage demanded a more sustainable irrigated agriculture. However, the ability to produce more food will depend to a large extent on improving existing irrigation systems and practices.

For the upper Awash basin, where irrigated agriculture is rapidly developing, potential evapotranspiration rate (consumptive use) of some food crops were computed using Penman method for a ten year average

Table 8 Maize irrigation amount and frequency trial (Melka Werrer).

Amount in cms	Yield (kg/ha)			
	Irrigation frequency (weeks)			
	1	2	3	Mean
7.5	4020	2810	1290	2700
12.5	4040	3540	2020	3200
17.5	4440	3870	2980	3760

Table 9 Haricot bean irrigation amount and frequency trial (Melka Werrer)

Amount in cms	Yield (kg/ha)			
	Irrigation frequency (days)			
	7	14	21	Mean
5	3800	1360	690	1950
10	3800	3480	2000	3090
15	3240	3460	2560	3090

LSD (0.05) Amount means = 482 kg/ha
Frequency means = 641 kg/ha

Table 10 Cowpea irrigation amount and frequency trial (Gode)

Amount in cms	Yield (kg/ha)				
	Irrigation frequency (days)				
	6	12	18	24	Mean
5	2490	2010	1480	1450	1860
10	2590	2690	1810	1990	2290
15	2220	2790	2740	2330	2520

LSD (0.05) Amount means = 210 kg/ha

meteorological data obtained from Wonji, 5 km from Nazret Research Station. The estimated seasonal consumptive use were 580, 560, 370, and 425 mm for maize, sorghum, haricot bean and cowpea, respectively. Now preparations are completed to verify these estimates using drainage lysimeters. On the other hand, optimum irrigation water requirement for some food crops are also carried out at Melka Werrer using field trials (IAR, 1971 and 19785). The result on maize showed a significant yield increase (P = 0.01) as the irrigation amount increased from 7.5 cm to 17.5 cm per irrigation and also progressively decreases as irrigation interval increases from 7 to 14 and 21 days (Table 8). The overall yield was low ranging between 1300 kg/ha to 4400 kg/ha. Significant yield differences ($P = 0.05$) were also obtained on haricot bean irrigation trial. However, yields decreased as irrigation amount and frequency increased from 5 to 15 cm and 7 to 14 and 21 days, respectively. These data showed that haricot bean is very sensitive to excess watering specially in the early stages. The yield ranged between 690 kg/ha to 3800 kg/ha with the highest yield observed from 5 cm at 7 days interval. Cowpea irrigation trial at Gode Research Station followed a similar trend as haricot bean trial at Melka Werrer. Significant yield differences ($P = 0.05$) were obtained between amount and frequency and the highest yield observed was from 5 cm every 6 days that gave 2500 kg/ha (Table 10). The effect of irrigation on five wheat varieties (white grain 8155, Yakatana 54, Panjams 62, Ketana Frontana × Mayo 84 and Froxor) were tested and significant yield differences were found between varieties. The highest yield response was from white grain. Other irrigation trials were on oil crops and cotton, and they are not reviewed here.

Conclusion

Improved seed bed preparation methods have proved to be effective in conserving soil moisture and increasing yield in the drought affected areas; Mekele, Quiha and Kobo of Ethiopia. Tie-ridges have increased yield of wheat, sorghum, cowpea and mungbean by 50 to 80%. The highest wheat yield for Mekele and Quiha was obtained from a spacing of 80 and 40 cm tie-ridges, respectively. However, constructing tie-ridges by hand is tiresome and time consuming for farmers and there is an urgent need for simple ridge forming implements.

The practical significance of mulching under Ethiopian conditions is very much limited due to the farmers practice of using crop residue for animal feed, fuel and construction purposes.

At Mekele soil loss from bare fallow was higher (18 tons/ha/yr) compared to grass covered (2.5 tons/ha/yr). Soil losses from cropped lands were moderately high. Wind erosion is also a major threat in the semi arid and arid regions and requires further study on practices to reduce its effect on crop production.

Irrigation water requirement trials on some food crops indicated trends to achieving optimum yield. However, the results were not impressive largely due to poor treatment level selection. The average productivity of drylands observed was in the range of 500 to 1000 kg/ha at farmers level of production, while in research stations, higher yields were in the order of 2,000 to 3,000 kg/ha. The difference is a measure of performance and indicates untapped potential for improving crop production in the semi-arid regions. Maximizing resource utilization and productivity is, therefore, vital and is an essential step towards food self-sufficiency. The results obtained so far are encouraging. However, more work needs to be done on land, water and crop management practices to keep pace with the increasing food demands in the future.

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37 An integrated approach to soil and water management in the arid and semi-arid regions of Kenya

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Abstract Kenya's potential for economic development depends on the stock of its natural resources and their management. More than 75% of Kenya's surface land is arid and semi-arid. This portion has a fragile ecology characterized by low, erratic rainfalls which fall with erosive down pours. Rainfall is therefore the major single element which constrains crop and animal production in these drylands. The soils here are shallow in depth with limited capacity to store water extractable by crops. The internal structure of these soils are poorly developed resulting in logging and excessive water runoff losses during heavy rain periods. They have poor structural stability so the soil particles are easily eroded and dislodged from fields. Along with the poor soils and low rainfalls, poor management practices on the soils is declining production. Hence famines feature prominently in these areas.

This paper discusses several ways of managing this fragile ecology to improve and sustain production in the long run. These methods will enhance infiltration, reduce runoff and conserve soil and water.

Introducton

The lowest population densities in Kenya lie within the semi and arid areas. These fall under the agroecological zones 4, 5, 6, and 7 and occupy over 75% of Kenya's total surface area. Agroecozones 4 and a part of the arid zone 5 have rainfall sufficient enough to support rainfed cropping. The agroecozones are suited to extensive grazing for beef production, sheep, goats, camels and wild game in the national parks. As is evident from the tables 1 and 2 the coast province, Eastern and Rift valley provinces have large portions of dry lands while small pockets of aridity occur in the high potential areas of Kenya. The proper management of these vast areas of drylands could solve Kenya's food production problem. The drylands possess a fragile ecology, first, the rainfall is limited in amount and erratic. The onset of the rainy season is irregular and the rain comes in heavy erosive down pours. There are characteristic lengthy drought periods. Rain is the main climatic element which constrain crop and animal production in these areas. Most of the rivers in the drylands are seasonal, and water is one of the major environmental problems in these areas.

Secondly, the soils are poorly developed, shallow and of poor structural stability. This means that they can be easily dislodged and removed by the runoff water. At the same time they have low organic matter due to the low vegetation cover and low inherent soil fertility.

Thirdly, the rugged topography, poor management practices e.g. overstocking, tillage practices and use of poor implements and charcoal harvesting have caused considerable suffering to the people living in these areas. The silting up of surface dams, erosion problems on arable and grazing lands have led to watershortages and declining yields respectively.

Table 1 Districts in Rift Valley, Coast, and Eastern Provinces with substantial area of drylands (zones, 4, 5)

Province/District	197 Pop., 000	Area of district in agroecological zones (sq. km)				Total[1]
		1-3	4	5	6	
Rift Valley						
S.E. Kajiado[2]	43	49	262	762	2,257	3,330
Narok	210	3,890	1,588	3,814	4,212	16,115
Nakuru	523	2,016	1,731	637	436	5,769
Baringo	204	520	1,456	3,440	1,769	9,885
Laikipia	135	443	887	4,287	2,479	9,718
West Pokot	159	801	164	2,674	1,292	9,090
Subtotal	1,274	7,719	6,088	15,614	12,445	50,577
Coast						
Kwale	288	1,188	897	2,342	2,886	8,257
Kilifi	431	443	2,098	2,658	1,914	12,414
Lamu	42	511	3,376	1,606	24	6,506
Taita-Taveta	148	158	545	1,791	3,348	16,959
S.E. Tana River	32	280	138	970	7,162	9,187*
Subtotal	941	2,580	7,054	9,367	15,334	53,323
Eastern						
Machakos	1,023	347	2,982	6,035	1,026	14,178
Kitui	404	25	2,877	10,166	6,996	29,388
Embu	263	418	330	1,266	–	2,711
Meru	830	1,931	935	1,651	805	9,922
Subtotal	2,520	2,721	7,124	19,118	8,827	56,202

[1] Totals include zone 7.
[2] These two districts are represented only by the southeast corner of each; land area figures do not include total district.
Source: Jaetzold and Schmidt (1982).

Fourthly, there has been population migration from the high potential areas to the dry areas in search of land for settlement and farming.

The paper describes attempts and proposals at the conservation of soil and water through an integrated approach in both grazing and arable drylands.

The conservation of the resources soil and water

For many years in the dry areas there have been several problems related directly to mismanagement of the above resources. Runoff water, raindrop impact remove the first few millimetres of soil which contain the plant nutrients with consequent declining yields for both crops and pastures. The sediments removed from grazing and cropped lands reach the surface storage reservoirs thereby reducing their life span, polluting the stored waters and causing human suffering through water shortages. Desilting the silted up reservoirs is a costly venture. These costs could be minimized by protecting the catchments from which water enters into the storage reservoirs. The general pattern in the drylands is that arable lands are better

Table 2 Districts in Nyanza, Western, Central, and Rift Valley with relatively limited areas of drylands (zones, 4, 5)

Province/District	1979 Pop., 000	Areas of district in agroecological zones (sq. km)				Total[1]
		1-3	4	5	6	
Nyanza						
South Nyanza	818	3,534	624	375	–	5,714
Kisumu	482	1,381	192	–	–	2,093
Siaya	475	1,719	359	20	–	2,522
Subtotal	1,775	6,634	1,175	395	–	10,329
Western						
Busia	298	1,254	95	–	–	1,626
Bungoma	504	1,768	224	–	–	3,074
Kakamega	1,031	2,520	19	–	–	3,495
Subtotal	1,833	5,542	338	–	–	8,195
Central						
Nyandaruma	233	1,578	410	97	–	3,528
Kiambu	686	1,071	177	174	–	2,448
Murang'a	648	1,253	555	–	–	2,476
Kirinyaga	291	545	401	9	–	1,437
Subtotal	1,858	4,447	1,543	280	–	9,889
Rift Valley						
Nandi	299	1,659	267	–	–	2,745
Kericho	633	3,179	175	21	–	3,931
Trans Nzoia	260	738	803	18	–	2,078
Uasin Gishu	301	2,062	719	–	–	3,478
Elgeyo Marakwet	149	832	396	350	0	2,279
Subtotal	1,642	8,470	2,360	389	–	14,511

[1] Totals include zone 7.
Source: Jaetzold and Schmidt (1982).

protected than grazing lands as is evident from the presence of heavy structural conservation work on many farms. Machakos District is a good example. Nevertheless, these structural conservation works have not been properly protected against destruction e.g. by animals and their lifespan has been short. Drought resistant grasses for terrace bank stability which also gives some feed to the animals when cut have been tested and their results will be given later in this paper. At the same time, different conservation structures e.g. graded terraces, level terraces grass strips, bank elements and contour tillage are also undergoing test for their effectiveness.

Grazing lands

In an effort to quantify soil erosion on grazing lands of the drylands, experiments on four catchments in Machakos district and one in Kitui district were done. In Machakos district the stocking rates are known to be very high. The vegetation cover on rangeland, both privately owned and communal land is very low. An estimate of 0.5-1.5 cm soil loss per year has been reported. Work done by Kinama in Kitui district reported a soil loss of 1 cm per year.

Katumani Research Station worked on vegetation cover in 1982/83. The data clearly show that a vegetation cover of 30% effectively reduces erosion to tolerable levels. However in catchments where vegetation cover was less than 30% a soil loss of 20-30 tons/hac/year was recorded. This clearly indicates the crucial role of vegetation cover in combating soil erosion.

The following methods are to some extent being used to rehabilitate denuded lands and protect the grazing lands.

i. Vegetation: The use, of drought tolerant grasses/tree species like *Cenchrus caliaris, panicum maximum, Cynodon dactylon, Leuceana leucocephala* and other acacia species. These are planted either in seed form or splits/seedlings.
ii. Fencing (dead and live fences): These protect the vegetation being established on denuded lands from domestic and wild animals. The use of cutoff drains to direct water from entering the denuded lands.
iii. Rotational grazing. This checks soil erosion of the paddocked blocks.
iv. Construction of fire breaks such that fires can be restricted to identified areas.
v. Construction of watering points at strategic places to avoid concentration of livestock and the resultant erosion leading to gully formation and denudation of areas.
vi. Encouragement of formation of group ranches where essential facilities like water, dips etc can be provided easily and monitoring of livestock numbers in relation to available forage is easy. This enables more accurate and realistic plans for grazing management to be effected.

Arable lands

Most dryland soils have a tendency to surface seal at the onset of the first rains leading to high runoff. Much land is cultivated twice a year and exposed to the most erosive rains during the early part of the growing season, before crops are fully established. Crop cover is poor due to lack of moisture or fertility or both. To reduce runoff and enhance infiltration on the cropped land soil conservation structures, tillage and other management aspects practised. Research work at Katumani was started in 1982 with a view to testing the effectiveness of the various conservations methods used by the local farmers. These were the "Fanya Juu" terraces, both level and graded, grass strips, bank elements and contour tillage as a control. Observations were made from the yield from each of the four plots where a moisture probe tube had been sunk. The movement of the soil was also observed.

The results from this experiment showed that terraced plots gave better maize yields than unterraced ones. This was associated with water collected from the rains and stored between the interterrace space. There was a tendency for more soil and water to collect at the lower end of the terrace. This gave more yields at the lower end than the upper end of the terrace.

Four drought resistant grasses and one legume were also tested for their effectiveness is stabilising the Fanya Juu terraces. These included (i). *Makarikariensis* (ii). *Cynodon dactylon* (iii). *Cenchrus celiaris* (iv). *Panicum maximum* (v). *Stylosanthes guyanensis*. The following results were obtained (Table 3).

Table 3 Results of Drought Resistant Grass tests.

Grass/Legum	A *Makarikanensis*	B *Cynodon dactylon*	C *Cenchrus celiaris*	D *Panicum maximum*	E *Stylosanthes guyanensis*
Establishment %	Good	Good	Good	Good	Good
Cover initial after	30	30	30	30	30
4 years	100	100	100	100	100
Maintenance labour per hectare	20 Mandays	40 Mandays	2	6	10
Availability in seed as splits	Plenty (Cuttings)	Plenty Splits	Plenty	Plenty	Plenty
Animal Palatability	Fair	Fair	Good	Good	Good

From the above test, Lands A were chosen on the grasses followed by D and E. The costs of maintaining them are fairly low and *Cenchrus celiaris* and *Cynodon dactylon* as the best grasses for reclaiming denuded lands and stabilising waterways due to their fast creeping abilities. The farmer can also cut these grasses A, B, and D and the legume E to feed his animals or even do some mulching. The creeping ability for *Cynodon dactylon* was found out to be about 10 metres per season making it unsuitable for use in crop lands.

Contour ploughing and early planting ensures that water is fairly distributed within the interterracial spaces resulting in *in situ* water conservation. Early planted crops then take advantage of the moisture from the early rains. There has however been lack of an appropriate tool for opening up the land during the dry season to facilitate early planting, leading to late planting and consequent water stresses over the growing season. Better tillage practices lead to enhanced infiltration, improved soil structure, reduce bulk density, control weeds, reduce runoff and reduce moisture loss by evaporation.

During dry periods and before the onset of the rains, soil conditions make land preparation difficult. The draught animals are also in their poorest conditions. These problems have led various scientists to improve on the existing tillage implement the mould board plough.

Several attachments to a multi-purpose tool frame have been developed by Katumani, University of Nairobi and others. The following attachments were selected for dryland operations.

i. Mould board plough
ii Cultivator frame
iii. Chisel plough
iv. Desi-plough
v. Rolling plant planter
vi Furrow opener-cum-ridger.

Generally these attachments help the farmer to achieve timeliness in land preparation and hence gain in utilising the limited available rain water. This on the whole helps the farmer achieve better tillage. Nevertheless, more research is required to improve on tilage in this field. The other management aspects include mulching, crop rotations, application of manure (organic and inorganic), appropriate plant population and inter-cropping and management of runoff water from roads and say rock catchments.

Mulches improve on the soil structure, conserve moisture, control weeds and reduce soil erosion through rain drop impact. This is a practice to be encouraged among farmers. However, there is high termite damage and animals feed on the stovers thereby limiting their use as mulches.

Analysis of soils called from the dry areas of Eastern Province show that they are deficient in N.P Cu and Zn and also quite low in organic matter content, and it is therefore necessary to use farm yard manure. Many farmers use farm yard manure in dry areas. According to Rukandema and Muhamed, in Mwala Machakos district 80% of the farmers own cattle and 68% of them use farm yard manure while 8% use mineral fertilizers. Ikombo in 1983 reported 8 tons/hac. as high and consistent yields of maize in both wet and dry seasons. More research is however needed to determine the optimal rate of application and the methods of application.

Limitations

A number of factors limit the applicability of some of the conservation methods in practice. These include.

a. The land tenure system
b. Financial and Technical draw backs and
c. Socio-economic problems.

Conclusions

In solving soil and water management problems in dry areas, there is a need to integrate all the methods of conservation both structural or biological. In doing this, more research and extension work is inevitable in realising these goals.

38 Agricultural Mechanization as a limiting physical technological constraint in agricultural production in the Semi-Arid Region of Nigeria

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Abstract Efficient production of food involves principles of biological technology (better seed, fertilizer etc) and physical technology (devices for timely planting, proper land preparation, proper crop storage). While the need of physical technology is accepted by planners, yet the major focus of agricultural development is mostly on biological technology.

This paper examines the fallacy of this approach as, most often, the major constraints are those involving aspects of physical technology like timely and proper land preparation, proper placement of seed and fertilizer, water and machinery management. This is most important in arid and semi-arid areas, which are prone to drought. A good biological technology can fail if the required physical technological aspects are not adequately considered. This paper concludes by giving the highlights of the agricultural mechanization research programme of the Institute for Agricultural Research, Samaru, Nigeria, and identifies some of the impediments to physical technology adoption.

Introduction

Nigeria has recently placed the highest priority on revitalizing agriculture in order to be self sufficient in food. Before the oil boom, the percentage of the agriculture sector to GDP was about 70 percent and Nigeria was exporting crops like groundnut, cotton, cocoa etc. Nigeria continues, however, to have a vast agricultural resource. Presently only about 34 million hectares of the 71.2 million hectares cultivable land is under cultivation, (Awoyemi 1985). Rainfall ranges from less than 500 mm in the extreme North to about 4000 mm in the South-east.

Projected food situation

With the scanty agricultural statistics, it is difficult to know the present food and agriculture situation in the country (Awoyemi 1985). A Nigerian Study Group of Food Production, compiled the position of few items given in Table 1.

Table 1 Projected Food Supply and Demand (10^3m tons)

Commodity	Projected Demand 1985	Projected Supply Domestic Production	Gaps
Rice	1,791	975	816
Maize	2,634	2,374	260
Sorghum	4,500	4,000	500
Millet	4,000	3,500	500
Wheat	1,830	145	1,685
Cassava	13,300	10,000	3,300
Cowpea	1,300	1,015	285
Groundnut	560	300	260

Food deficit and drought

There is thus an obvious food deficit which has necessitated importation of several items. Against a deficit food situation any process that involves a demand on food further aggravates the situation. In a drought condition, this becomes more crucial in order to avoid a famine.

Many theories about the occurence of drought have been given. These range from 'act of God' to outcome of 'global changes in pressure condition' and 'a long-term phenomenon'. Some see drought as cumulative detrimental act of people. The detrimental effect supposedly affecting the rainfall and leading to drought have been summarized as: (Apeloddorn, 1978)

i. Removal of top horizon of soil which change the reflective index of surface.
ii. Creation of dust in the atmosphere by burning, overcultivation etc which absorbs incoming radiation and subsequent reduction of rain.
iii. Creation of industrial pollution (carbon dioxide) causing climatic changes.
iv. Depletion of organic decay product by overgrazing leading to reduction of precipitation.
v. Increase in population and consequent pressure on land causing environmental imbalance.

Because of above actions, the following implications are obvious:

a. Actions resulting in damage to environment make same amount of rainfall less effective through *erosion* and *reduced water retention* by soil.
b. In view of limited rainfall and its uncertainty, *timeliness of operations* is very crucial to ensure yield advantage.
c. Because the available 'growing season' is short, crops and varieties demanding *short growing cycle* will undoubtedly do better than long duration varieties.

Agriculture as an industry

Agriculture is a large industry involving several operations and processes. Raising of crops broadly involves two types of technology. The physical and the biological. The physical technology covers generally the aspects of agric. mechanization, involving operations and equipment from land clearing to final crop processing and storage. Biological technology covers areas like varietal improvement, plant population, fertilizer and pesticide formulations etc.

Both forms of technology are needed to make an overall improvement in any farming system. A close examination of the various factors that influence agricultural production would reveal that it is subjected to a complicated action and interaction of several un-controlled and controlled processes. Un-controllable processes include climate droughts and other natural vagaries of nature. The controlled processes include 'inputs' to agriculture and these are: fertilizers, seeds, water (irrigation), pesticides and farm equipment. It is the delicate interaction of all the biological (seed, fertilizer etc) and physical (farm-equipment etc) inputs that finally influences overall production.

Mechanization as an essential physical technology based input

Mechanization as an input can indirectly influence the effect of climate etc depending on how it is implemented. However, there are some aspects of production where mechanization is essentially required – irrespective of the level of farming. These are briefly indicated below:

Application of chemicals for plant protection

Due to nature and dosage of chemicals involved, some type of machine must be used, it may be a simple syringe or the most sophisticated aerial sprayer.

Operations beyond capacity of human power

Some type of machine/power unit has to be used to handle situations where human power is limiting. eg.

i. working the soil in the dry season when it is not possible to handle manually.
ii. bringing additional land under cultivation. With a hoe there is a limit to which a man can work his land. Additional land, to be cultivated, would need bigger power units (such as animal power, tractor, electric) and appropriate equipment.

Timeliness

Where certain operations are to be achieved within a stipulated time, to ensure optimum growth or minimum loss, the use of suitable machinery with appropriate power is obvious. This is, however, assuming that beyond some point, labour is a limitation and the task is such that all of it cannot be done by human power, within the available time.

Placement of inputs

Sometimes farm equipment is referred to as an 'input' to 'input'.

Usually the other inputs like seed, fertilizer etc. demand precision placement in relation to quantity and location and a machine becomes a very essential component.

Ease of work-relief from drudgery

Every farm worker, aspires to find some way to ease his work. This is another aspect where mechanization is required.

Physical technology: Improper application

Re-examination of crop production in the arid and semi-arid areas, shows that water deficit is the principal constraint and in most situations, farmer and his family act as the main source of power for the various farm operations. In the traditional system, there appears to be some balance between the area controlled and protection from effect of weather fluctuations. This is usually done by such techniques as fallow cultivation, mixed cropping and exploitation of early rains by traditional techniques of making planting hills in the furrows between existing ridges.

Approaches at improving agricultural production in Nigeria have been made through the following methods:

i. *Clearing land for increased hectarage*
This has been usually done through state Tractor hiring units, which tend to have limited expertise. The result has been removal of trees along with a valuable top soil. Often the tree stumps are left in the field making later operation to be difficult for subsequent machines. There is high rate of machine breakdown and other difficulties which are associated with this approach.

ii. *Setting up of River Basin Authorities*
Large irrigation schemes have been set up in which farmers are given assistance in land preparation and irrigation water and limited assistance on harvest and post harvest operations. Lack of appropriate soil-water management at most of the basins has resulted in new problems like salinity and water logging.
Similarly sinking of bore holes without proper knowledge of water resources being tapped can be disastrous in the long run.

iii. *Large Scale Mechanized Schemes*
Several attempts have been made to run large scale mechanized farms and schemes like, Niger State project, were aimed to farm about 13,000 hectares of land mostly to grow groundnut and sorghum.

Drought prone activities

Indiscriminate land clearing exposes the area to erosion and desert encroachment. To counteract this, massive afforestation schemes have been initiated all over the Federation, redoing essentially what was not necessary if initial care in land clearing was taken.

Improper water management practice can start right from construction of dam and the distribution of water from the dam to the farmers. Construction of a dam for irrigation water is, in simple terms, like providing a storage tank. However, size selection and location of a dam is in itself an intricate physical technology. Current apprehensions remain about their satisfactory design in relation to years when rainfall is far below average due to lack of adequate climatic and other data for such designs.

Having made a dam, is only a fraction of what it takes to operate the system efficiently in terms of actual release of water to farmers. From the dam the water is subjected to a network of distribution system; both from the dam to the irrigation site and the actual user farm. There can be expensive water loss at several of the outlets. In a study done at Kadawa in Northern Nigeria, it was revealed that efficiencies of conveyance, water application, and water disitribution were of the order of 26.0%, 61.90%, 86.35%, respectively. (Adewumi 1985). The overall efficiency was a ridiculously low of about 14%. This poses a serious challenge to the wisdom of building expensive dams with no satisfactory system for its utilization at the actual farmer level.

Similarly excessive irrigation water can generate problems of salinity. For example, the Kano river project which covers over 62,000 hectare of land, was experiencing water table seldom within 1.5 m of ground surface even during rainy season, before the project started. The situation has changed due to excessive irrigation and the water table comes to within 40 cm of soil surface during irrigation season (Nwa 1982). This has resulted in crop failures at several areas and there is now no difference in irrigation scheduling in such areas. Though better irrigation is possible but undoubtedly it calls for an appropriate drainage system for the area and demand a physical technological solution.

Agricultural Mechanization Work at the Institute for Agricultural Research (IAR)

The Institute for Agricultural Research (IAR) which is one of the national research institutes covering Northern Nigeria, has focussed attention primarily on problems of small scale farmers. The Institute mandate crops are sorghum, millet, maize, wheat, barley, cowpea, groundnut, tree and horticultural crops. The institute operates through several multi-disciplinary research programmes but the major input to physical technology development is through the Agricultural Mechanization Research programme. The mechanization programme has been operated on three sub-programmes:

i. Machinery Evaluation
ii. Machinery Development
iii. Machinery Management.

Machinery Evaluation

Since almost all equipment in use is imported into Nigeria, technical evaluation, under local condition, had been undertaken at the Institute to guide the user. Nearly 30 Technical Test Reports have been released which has to some extent stopped the importation of unsuitable equipment and motivated some manufacturers to make changes in their design to suit local farming systems. Some of the features detected in imported equipment which made them unsuitable for local use in Nigeria include the following. (Kaul, R.N. et al., 1983)

Tractors

i. Small (walking and ridging type) tractors generally have constraint of:

a. low clearance, especially for local ridge spacing and cultivation practice.
b. wheel tread adjustment limits are not flexible enough to suit local crop spacings.
c. there is difficulty in steering.
d. these have inadequate power, especially for dry season cultivation.

ii. Higher powered tractors are not usually supplied or given – recommended matching implement especially for post-tillage operations.

Crop Protection Equipment

Reports reveal the extreme variation of power consumption in CDA equipment (that would reflect on battery needs); the variation in volume mean diameter and droplet size and leakage/spillage of chemicals, among other factors of performance. Some newer development, like the "Electrodyn" sprayer had limited use in mixed cropping and thick crop canopies, like cowpea.

Post-harvest machines – Thresher/shellers

Some deductions from technical test reports are:

i. The machines were claimed to have wide applicability for diverse crops – maize, sorghum, millet, etc.
   Usually at best they are good for a single crop.
ii. Output is usually 50% or less than what is claimed.
iii. Losses are very high – usually due to varietal and environmental effects. The design does not generally provide adquate flexibility of adjustment.
iv. Machines are sold without adequate provision of power and drive units resulting in further mismatching or non-operation, in local situations.
v. Price payable by the farmer is very high.

Specific highlights from some of the reports are given below:

Test Report 83/26 on Bolgar Tractor

The tractor was not found technically acceptable and in fact proved an out of production model in the country where manufactured. Our report assisted a state government to decide against intended importation of 350 tractors.

Report No. DAE/79/7 on Maize Shellers

Evaluation of 3 maize shellers (Nogeuira SDMN – 15/35, Ransome LION and Ransome Cobmaster) revealed, among other things, the following:

- The Nogeuira SDMN – 15/35 gave seed losses ranging from 3.6 to 24.6% while no losses were claimed by the manufacturer.
- The Ransome Cobmaster gave a maximum output of 376 kg/seed/hour as against the manufacturer's claim of 900 kg/hour. In addition it needs dehusked cobs which makes it labour-intensive and this aspect could have escaped user attention.

- The LION Sheller though reaching 3 ton/hour capacity cannot fit into existing farmer practices and in essence gave an average output of only about 1 ton/hour, defeating the purpose of a high output. A medium sized, thresher (about 1 ton/hour) would have cost less than half of a 'LION' Sheller.

iii. Report No. DAE/81/23: Comparative Evaluation Herbicide Applicators

In comparing 4 applicators (Micron Herbi, FW Handy, Besthoud Cr and Turbair) it was seen that power consumption varied from a low of 0.6 watt (Turbair) to nearly 3 times for the other three, implying the savings on battery life possible by proper selection of the applicator. There was also variations in droplet size, and variation in output (as tank empties) which are of critical importance in spraying operations.

iv. Report No. DAE/81/20: Arara Equipment

The technical assessment of set of implement (multi-purpose cultivator, planter and pod stripper) provided with the Arara frame showed the cultivator promising but the planter and pod stripper were not suitable for local requirements.

A summary of Test Report already released (Kaul R.N. et al 1983) is documented in a report entitled "Test Report Summaries – Report No. IAR/AM/83-1". This gives highlights of various machines tested at the Institute and is available on demand.

Machinery Development

As a long term solution to small scale mechanization, the Institute for Agricultural Research, Samaru has developed many prototypes of machines which can be fabricated locally. Some of these are briefly stated below:

Manual Operated

- *Maize Sheller*
  A hand held cone with internal serrated ribs shells maize cobs when rotated in the cone. The smaller and larger cone can be used to feed small or large size covers respectively.
- *Groundnut Decorticator*
  A rotating cylinder with shelling bars (of wood or cast iron) achieves shelling when rubbing groundnut pods against a stationary but slotted concave. Shelled kernels fall through the concave along with shell which can be separated by manual sieves. The cylinder can be cranked manually or by a foot operated lever.
- *Cowpea Thresher*
  A unit similar to groundnut sheller has been developed for Cowpea threshing.
- *Ground metered shrouded spinning disc applicator*
  This involves shrouding a commercial (Herbi) CDA applicator and using a peristaltic pump to deliver liquid to the spinning disc. In addition the distribution pattern of the spinning disc is more uniform.
- *Mango Picker*
  This consists of a harvesting ring which is mounted on a long pole. The

ring has rope mesh attached to it. Plucking of fruits is done by the ring when rubbed against the fruit stem and the detached fruit falls in the basket.

– *Animal Operated*

Amongst the animal operated prototypes developed, the following are more promising ones:

High Clearance Straddle Row Weeder

Straddle rotors are mounted on a high clearance frame to give working clearance upto 1 meter crop height. Weeding is done by rotors which straddle the ridges and weeds are best eliminated at 2-3 leaf stage.

Weeding Attachment on Emcot Ridger

These are similar to straddle row weeder rotors and 2 such units are fitted to the commercially available Emcot ridger. It is effective for 90 and 76 cm row spacing.

Tractor/Engine Operated

Some prototypes using engine or tractor power as the prime mover have been developed. These are:

Multicrop Thresher

A monoaxle type using peg cylinder and adjustable stationary concave has been developed to suit a 3.5 kw power source. Cleaning is accomplished by a set of reciprocating sieves and an aspirator. The machine can thresh three crops: sorghum, millet and wheat with appropriate change of drive speed and a sieve.

Grondnut Thresher

A prototype using about 2 kw power unit and employing a cylinder concave with vibrating sieve system has been developed. Stemmer saws ensure chopping of vines for ease of separation.

Table 2 summarizes the output advantages of some of these machines over the traditional method.

iii. Machinery Management

The third activity of the IAR mechanization programme is to study various aspects of machinery management. The focus of this sub-programme is proper management of equipment. Such studies have, for instance, revealed that:

- It is not possible to use tractors before the rains have well set and as such the advantage of early rains (as practiced in traditional system) is not possible with currently available equipment. Similarly during excessive rains there is wheel traction difficulties.
- Field losses can be high if the proper size and type of equipment is not used. For example, field studies at an irrigation site near Kadawa (Northern Nigerian) put losses for a combine harvester as high as 25%.
- Equipment (power source and implement) need proper matching to economise on fuel etc. in addition to proper hitching.
- Crop production should be treated in its full cycle as the mechanizing of one operation may throw the other operation into disarray.
- Tractor and other equipment hours should be increased to ensure economical usage. For instance at 3 farm centres records in Kaduna State (Northern Nigeria) show that average yearly usage hours were (IAR, 1984, 85):

Table 2 Some of the prototypes developed at IAR and their advantages over traditional method.

Prototype machine	Operations performed	Prototype out-put kg/man-hour	Traditional method out-put kg/man hour	Output advantage over traditional (%)
Multicrop Thresher for	Threshing and and winnowing			
– Wheat	"	40	5	800
– Sorghum	"	30	20	150
– Millet	"	30	15	200
Groundnut Sheller	Shelling and partical cleaning	30	1	3,000
Groundnut Thresher	Picking of pods from harvested plant	30	3	1,000
Straddle Row Weeder	Weeding on ridges	0.1 (ha/hr)	0.02 (ha/hr)	500
Maize Sheller (Manual)	Shelling of Maize	14	9	150

Other machines in process of development are:
Solar powered crop drier – Expected to cut down drying time by at least 50%
Sorghum harvester – Presently a manual operated unit is being developed.
Transport aids – Attachments to bicycle, and animal powered unit.
Animal powered land leveller.

Zonkwa – 317
Kafinsoli – 201
Saminak – 429
Average – 316 hour/year

Tractors should also be operated near their rated capacity to obtain maximum efficiency. Only ploughing and disking demand full power from tractor. The rest of the time it works on partial load. In a study elsewhere (Hetz 1985) it was shown that fuel savings upto 30% can be obtained by reducing engine speed to 80% of rated speed and shifting to a higher gear to maintain desired field speed.

In another survey (IAR 1984, 1985) the average utilization factor, defined as the ratio of *Actual load carried per trip to the Max. load the device can carry per trip*, for animal, bicycle and motorcycle as transport devices was respectively 0.44, 0.40 and 0.38. This suggested that increasing load carrying capacity with better management for the same transport device.

Invovlement of relevant physical technology

There is now a need for greater involvement of physical technology to offset the constraints of production unless the physical constraint are removed the biological input will not be fully realised. For instance if timeliness of operation (so crucial in semi-arid regions) is not done the best variety will not produce yields. Similarly the limited available fertilizer, unless 'placed' properly will not give full benefit to crops.

Similarly design of farm level storage, is more crucial in drought prone areas so that grain movement is easier and a famine can be avoided during drought.

Physical technological solutions are also needed in methods of farm waste disposal or recycling; fuel efficient wood/charcoal stoves, alternate energy method and rural (farm level) transport devices.

Some impediments to physical technology adoption

There are few factors which have acted against adoption of physical technology. Some major ones are:

Treating mechanization without considering the system

Attempt at mechanization have been done without seeing its effect on the system, e.g. tillage in isolation has by far received the maximum exposure to mechanization. This even led to establishment of tractor hiring schemes. Apart from over subsidised costing (which made them uneconomical to sustain the scheme) there was no satisfactory arrangement to provide assistance in other farm operations like weeding, threshing, etc. with the result that farmers generally felt discouraged with this service.

Heavy focus on large scale farms

Whenever any serious attempt on mechanization is being made, considerable focus appears to be given is setting up large farms. It is only recently that through ADP's small scale farmers are receiving attention and this aspect needs further strengthening by adoption of small scale equipment developed at various research institute like IAR.

High price of equipment in relation to farmers buying potential

The cost of agricultural equipment is too high in relation to buying potential of farmers concerned. Since farmers income is mostly through sale of crop produce, it is better to get an idea of relative cost of machines in terms of crop price.

In some countries, like Nigeria, even though the ex-farm price (US $ per ton), as below may be high in relation to world market, but the low yields offset this aspect (GegoArno 1986).

Country	*Price per ton US $ (ton)*
Japan	1342 (1981)
South Korea	736 (1981)
Indonesia	169 (1978)
Malaysia	462 (1979)
Egypt	121 (1981)
Nigeria	562 (1981)
World Market	270 (1981)

Thus in Nigeria to buy a medium size tractor the price is about 40 tons of paddy which is beyond the reach of an ordinary farmer having low hectarage and poor yields.

Intercropping – Demands specific farm equipment

Most small scale farmers practice intercropping which sets in constraints for use of machinery due to complicated spacings and varied crop mixtures. Experience has shown that some recommended mixtures are practically impossible to mechanise (Kalkat et al 1986). An integrated research with agronomists call for recommendations which can be mechanised to suit small farmer conditions.

Lack of standard to compare performance of imported equipment

In Nigeria there are hardly any standards developed for agricultural equipment by the Nigerian Standards Organisation. Lack of such standards prevents any comparisons to single out equipment which can be of acceptable limit. It is difficult to visualise from acceptable limit and the manufacturer's/dealers have a field day sending in all types of equipment as the most suitable for Nigeria.

Non-involvement of private sector with research Institute

By and large most of the manufacturers lack any sound research and development (R&D) unit of their own. There is also limited collaboration between the research institute and manufacturer especially those making small scale farm equipment. This is contrary to approach in most developed countries and could be a reason for lack of mechanization growth in the country.

International Understanding

Mechanization efforts in developing country would not have suffered so much, but for lack of so called international ethics from exporting countries of sub-standard and irrelevant equipment. Such sub-standard equipment takes away farmers interest in accepting equipment. Need exists to create an international understanding so that no equipment is exported unless it is tested and found suitable in the country where it is being exported to.

Management Constraint

Mechanization has not made steady progress due to lack of adequate management. An unplanned mechanization strategy has done more damage to progress of its adoption. Similarly the dealer service is woefully missing. An example of (FMIRS, 1975) a good back up service is illustrated by Kubota Ltd. To quote "If an order is given and shipping direction is made in morning, the article is ready to ship in the same day and sent by private car, direct mail or airmail so it gets to service station next day and to the retailer within 3 to 4 days at the latest". How much of this service can be provided in an export service is anybody's guess. But the point is obvious. When such a machine is imported in a country, without similar back up services its performance is bound to be different than in homeland.

Conclusion

Above has given a brief overview of the mechanization situation. The few additions of tractor/animal drought equipment, is more of cosmetic significance when considered against totality of farmer population especially the small scale one where generally we are at nearly same level as 5 decades back.

More concerted efforts are necessary to ensure that planners take note of physical technology constraint and rate it generally a matter of overriding constraint to development. Otherwise we will continue to remain as a low priority input in farming cycle and create constraint of production, irrespective of large strides being made on the biological technology.

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39 Agronomic practices for reducing drought stress and improving maize grain yield in the semi-arid tropics of West Africa

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Abstract The semi-arid Tropics of West Africa (Northern Guinea, Sudan and Sahel Savanna zones) are characterized by a monomodal rainfall distribution pattern. Total annual rainfall ranges from 300 to 1200 mm and the length of the moist period from 2 to 5 months. The predominant soils are Alfisols (Ferruginous Tropical Soils), characterized by sandy topsoil textures and a textural B horizon of clay accumulation.

The IITA/SAFGRAD Maize Agronomy Program, based at the Kamboinsé Research Station (Burkina Faso), started in 1979. The research effort has concentrated on the Alfisols of the Sudan Savanna. The major agronomic factors limiting maize production (soil fertility, soil compaction and the risk of drought stress) are discussed.

Results show that the risk of drought stress can be reduced and maize grain yields increased by the following practices: a) Soil tillage, b) Tied ridges, c) Shallow ditches, d) Cultivations, e) Planting of maize on lower slope and hydromorphic soils, f) Use of crop residues as mulch, g) Use of varieties whose maturity fits the length of the growing cycle, h) Appropriate planting dates.

A summary of results of other agronomic studies conducted by the Program gives the effects on maize grain yield of the followng factors: planting depth, seedbed, earthing up, plants/hill, seed size, plant density, thinning date, spatial arrangement, effect on carbofuran, and others.

Introduction

Climate and Soils

The West African Semi-Arid Tropics (WASAT) can be separated into three major zones: the Sahel, the Sudan and the Northern Guinea Savannas, all of which are characterized by a monomodal rainfall distribution pattern. There is ample variability among different authors as to the terminologies and parameters used to define these zones (Cocheme and Franquin, 1967; Jones and Wild, 1975; Ahn, 1970) Charreau, 1974; Lawson and Juo, 1979). In this paper, the following limits are used (Table 1).

The *moist period* includes only that part of the rainy season when rainfall is more than half the potential evapotranspiration (Kassam et al, 1976).

Given the large variability in total rainfall and its distribution from year to year, this classification should not be interpreted rigidly. The moist period in the Northern Guinea Savanna is from May to October, whereas it begins later and ends earlier in the Sudan and Sahel Savannas.

The predominant soils in the WASAT are Alfisols, followed by

Table 1 Classification of the West African Semi-Arid Tropics on the basis of rainfall.

Savanna	Annual rainfall (m)	Length of moist period (months)
Sahel	300- 600	2-3
Sudan	600- 900	3-4
Northern Guinea	900-1200	4-5

Inceptisols, both accounting for more than 60% of the total acreage. Other Soil Orders less commonly found are Entisols, Aridisols, Vertisols and Oxisols. The so called Ferruginous Tropical Soils are mostly Alfisols whereas the Weakly Developed Soils are mostly Inceptisols. The Hydromorphic Soils (less than 10% of the total area) are widespread in bottom lands and have variable characteristics not associated with a particular Soil Order. (Sources: Jones and Wild, 1975; Ahn, 1970; Lawson and Juo, 1979; Charreau, 1974).

Ferruginous Tropical Soils occur widely between the 500 and 1200 mm isohyets; i.e. in the Northern Guinea and Sudan Savannas; but are relatively less common in the Sahel Savanna. These soils are usually fairly shallow. Because of the downward movement of clay within the profile, the surface soil tends to have a sandy texture, with low organic matter and low base exchange capacity, whereas the subsoil tends to be compact due to the accumulation of clay. Free iron oxides are commonly separated and deposited in the profile as mottles, concretions, or even as a hardpan (Jones and Wild, 1975).

Ferruginous Tropical soils have low topsoil clay contents (around 10%), but variable (0-25%). The predominant clay is kaolinite, but illite is sometimes present. This, together with the low organic matter contents (usually below 1.5%), accounts for the low cation exchange capacities (1-10 me/100 g) (Jones and Wild, 1975).

Maize Culture in West Africa

Traditionally, maize has been a more important crop in the humid Forest areas and Derived Savanna areas than in the Semi-Arid Savannas of West Africa. Thus, in 1976, Kassam concluded that in the north, maize had never become a major grain crop because of the importance of sorghum and millet in the Guinea and Sudan Savanna (Kassam, 1976). However, maize cultivation has been moving northwards from the Forest to the Savanna zone, slowly replacing sorghum and millet as the main cereal crop. In the Northern Guinea Savanna, maize is generally grown in fields that do not necessarily receive an intensive management from the point of view of manure or crop residue applications. It has become the major cereal in this ecology in countries like Nigeria and Ghana. In the Sudan Savanna, maize tends to be grown mostly as a compound or garden crop (Kassam, 1976), i.e. in fields adjacent to the houses, where both the soil physical and chemical properties have been improved by the continuous addition of household refuse, animal manure and crop residues; sometimes maize is also grown on hydromorphic soils (Lawson and Juo, 1979). In the Sudan Savanna, maize is important as a crop to fill the hungry period before the sorghum and millet harvests, but its role is minor in terms of acreage (10% or less of the area planted to sorghum and millet in Burkina Faso). Maize is grown sole or intercropped in the Northern Guinea Savanna, whereas it is mostly grown sole in the Sudan Savanna.

A complete review of previous maize agronomic research in the WASAT cannot be presented here. Although maize has been a less important crop than sorghum and millet in the region, some research effort has been carried out, mostly in the Northern Guinea Savanna and very little in the Sudan Savanna.

Nicou (1979) reviewed maize studies conducted by IRAT in West Africa since 1961. Many of these studies were not within the SAT. From the studies in Senegal, he concluded that an early planting after the rains are established was better than planting 15 days later. Moreover, it was better to plow before planting than to plant wthout plowing. On leached Ferruginous Tropical soils, plowing was very effective in increasing soil porosity, root density and maize yield. Similar results of plowing on maize yield (40-50% increase) were obtained n Burkina Faso on Weakly Ferrallitic Soils.

Kassam (1976) presented an overview of maize culture in the WASAT with emphasis on ecological considerations. Many studies on the effect of planting date were reviewed and it was not yet clear why planting date has such a pronounced effect on maize yield, although in some cases it is due to moisture shortage at the grain filling stage. Responses to nutrients varied from area to area, but rates of 100-175 kg/ha of N and 60-150 kg/ha of P_2O_5 were applied in the Northern Guinea Savanna for yields of over 5 ton/ha. Rates of 60-120 kg/ha of N and 40-100 kg/ha of P_2O_5 were applied in the Sudan Savanna for yields of over 3 ton/ha.

For Kassam et al (1976), the application of simple but improved technology can result in increased levels of production of maize and other crops in the Sudan Savanna. In general, pest and disease problems are relatively mild.

In their excellent review of the maintenance and improvement of the fertility of West African soils, Jones and Wild (1975) concluded that there are three essential components: a) maintenance of the existing stock of topsoil through carefully planned erosion control; b) maintenance of the existing stock of crop nutrients by conserving those already present, and by replacing through fertilizer use those taken out of the system by leaching and crop export; c) improvement of the soil as a physical medium for crop rooting by appropriate tillage operations and moisture control.

Studies conducted at Samaru, Nigeria (Northern Guinea Savanna) showed that, although total annual rainfall was adequate to grow good crops of cotton, yield may be limited by shortage of moisture due to high runoff water losses if measures are not taken to prevent it. Soil treatments that prevent soil 'capping' improve water infiltration and reduce runoff. Maximum rainfall retention was ensured by using tied ridges. Although tied ridges alone may lead to reduced yields in seasons of heavy rainfall, holding all the rainfall has never been shown to be disadvantageous at Samaru provided infiltration is good (Lawes, 1961).

Although some maize is grown in the Sahel Savanna under very special soil or management conditions, the acreage, relative to that of millet and sorghum, is very minor. In the remaining part of this paper all references to maize culture in the WASAT will apply to the Sudan and Northern Guinea Savannas and exclude the Sahel Savanna. Nevertheless, it is realized that some of the problems and solutions discussed could also apply to the latter.

Agronomic factors affecting maize production

The main agronomic factors affecting maize production in the predominant soils of the WASAT are soil fertility, soil compaction and the risk of drought stress. Other factors of lesser importance or of a more localized nature are: termite damage, maize streak virus, weeds (including the parasitic weed *Striga* spp) and lodging (Rodriguez, 1985).

Soil fertility

The soil fertility problems relate mostly to phosphorus and nitrogen deficiencies, associated, respectively, with low contents of total soil phosphorus and low organic matter contents.

Soil compaction

The problem of high soil compaction can be related to the following factors:

i. Mineralogy: high contents of quartz and kaolinite with low contents of amorphous iron and aluminum oxides
ii. Low organic matter contents
iii. Systematic removal of crop residues
iv. Lack of soil tillage
v. Impact from intense rainfall

Drought stress

The risk of drought stress is often high, especially in the Sudan Savanna zone, due to:

i. Low rainfall. Rainfall is equal or greater than evapotranspiration only in 1-4.5 months of the year
ii. Erratic rainfall distribution patterns. Dry periods of 1-2 weeks or longer during the growing season are common but unpredictable. Moreover, rains may be established late or cease earlier than expected.
iii. Soil surface sealing and/or crusting. The consequences are lower infiltration rates and increased runoff losses. This problem is aggravated in those areas of high population density and high soil degradation.
iv. Soil or subsoil compaction. As a result, percolation and infiltration rates decrease.
v. Low available soil moisture. This is a consequence of low available water capacities (related to the low clay and organic matter contents) and shallow soils.

The IITA/SAFGRAD Maize Agronomy Program

The IITA/SAFGRAD maize agronomy research started in 1979 and has concentrated on the Sudan Savanna of Burkina Faso. More than 240 field trials have been conducted. Most of the work has been conducted at the Kamboinsé Station. Other research sites are the Saria Station, Loumbila, Farako-Bâ, and farmers fields.

The Kamboinsé Station is located as 12° 28′ N and 1° 33′ W, at 300 m altitude (about 14 km NE of Ouagadougou). The mean annual rainfall is 800 mm, with a moist period that extends from June to mid-September. August is usually the wettest month in terms of both total rainfall and number of rainy days. The predominant soils are Alfisols and Inceptisols. The latter are found on the bottom lands, on the lowest part of the toposequence.

The soils at the Kamboinsé station (excepting the hydromorphic soils on the bottom lands) have typically the following characteristics: (a) a loam to sandy loam texture, with about 12% clay, 30% silt and 58% sand; (b) less than 1% organic matter; (c) a C/N ratio around 11; (d) a pH(H_2O) around 6; (e) about 2.3, 0.8, 0.21 and 0.11 meq/100 g of exchangeable Ca, Mg, K and Na, respectively; (f) 12 ppm of available P (Olsen); and 7 total P contents of 80-160 ppm.

The Saria Station has a latitude of 12° 16′ N, a latitude of 2° 9′ W, and an altitude of 300 m (about 90 km West of Ouagadougou). With an annual rainfall of 850 mm, it has similar pedoclimatic characteristics to those of the Kamboinsé Station, although the soil clay content is somewhat higher (about 18%). Loumbila is located 15 km NE of Ouagadougou and has a mean annual rainfall of 800 mm.

Soil bulk densities at Kaboinsé and Saria are often between 1.4 and 1.5 g/cm^3; they tend to decrease in the bottom lands and to increase with depth. Final (equilibrium) water infiltration rates are often in the order of 2-5 cm/hour.

Soils at the different trial sites were classified according to the French classification system and the Soil Taxonomy (Smaling, 1985). The following equivalences were found (Table 2).

Table 2 Classification of soils at experimental sites in Burkina Faso.

Locality	Soil Taxonomy	French class. System
Kamboinsé	Paleustalfs	Ferralitiques faiblement désatures
	Paleustalfs	Ferrugineux très lessivés
	Plinthustalfs	Ferrugineux très lessivés
	Ustochrepts	Hydromorphes peu humifiés
Saria	Plinthustalfs	Ferrugineux très lessivés
	Haplustalfs	Ferrugineux très lessivés
	Haplustalfs	Hydromorphes minérals
	Ustochrepts	Ferrugineux très peu lessivés
	Eutrustox	Ferrallitiques faiblement désaturés
Loumbila	Hapludalfs	Ferrugineux très lessivés
	Plinthustalfs	" "
	Ustorthents	" "
	Haplustalfs	" "
Farako-Bâ	Eutrustox	Ferrallitiques faiblement désaturés
	Ustorthents	" " "
	Haplustalfs	" " "
	Paleustalfs	" " "

Summary of research results of the IITA/SAFGRAD Maize Agronomy Program

Soil Fertility

Nitrogen. Grain yield response to nitrogen fertilizer was strongly dependent on the amount of rainfall received. Responses were found with up to 100 kg N/ha in the Sudan Savanna and up to 150 kg N/ha in the Northern Guinea Savanna (IITA/SAFGRAD, 1984). Recommendations to farmers should, however, take into account soil type and management history, removal of crop residues, rainfall in the preceding year, economic and other risk factors.

Timing of nitrogen application. Experiments in the Sudan Savanna with ferruginous tropical soils showed no consistent difference in grain yield between one total and several split nitrogen applications. On ferrallitic soils in the Northern Guinea Savanna split nitrogen applications generally produced better yields than one single N application at or soon after planting (IITA/SAFGRAD, 1985).

Legume-maize crop rotations. Maize grain yield was higher when maize followed cowpeas or groundnuts than when under continuous maize. However, the grain yield differences were small (150 to 700 kg/ha) and could not be attributed solely to increased nitrogen fixation by the legume, implying that other factors were involved in the positive rotation effect (IITA/SAFGRAD, 1983).

Phorphorus. Phosphorus deficiencies are widespread in Burkina and are a greater factor limiting yield than nitrogen. Deficiencies can be corrected, however, with moderate amounts of fertilizer application. Grain yield responses were found with up to 50-75 kg soluble P_2O_5/ha (IITA/SAFGRAD, 1984). In addition, marked residual effects of phosphorus on grain yield were measured several years after its initial application.

Use of local phosphatic rock. Experiments with the local phosphatic rock (Burkina phosphate) indicated its effectiveness in increasing grain yield during the first two years of application was very minor due to its low solubility.

Soil Compaction

Soil compaction affects maize growth and yield in at least two ways: (a) reduced root growth, with its related effects on water uptake and mineral nutrition, and (b) reduced water infiltration. Tillage and crop residue management were shown to reduce the negative effects of soil compaction on yield.

Soil tillage. In the absence of tied ridges, soil preparation by tractor, oxen, donkey, or hand-hoe always gave higher maize grain yields than zero-tillage. Generally, grain yield is positively correlated with depth of soil tillage. As such, tillage methods can be ranked as tractor > oxen > donkey = hand-hoe (IITA/SAFGRAD, 1981; IITA/SAFGRAD, 1984).

Residues. Crop residues help in maintaining soil organic matter and promote a higher level of biological activity. In particular, termite activity at or near the soil surface was found to be greatly enhanced by the presence of crop residues. As a result, infiltration rates and soil aeration are improved. When residues are kept as a mulch, an additional positive effect on maintaining lower soil temperatures and minimizing evaporative losses can be expected. Marked effects on maize grain yield were obtained only when the amount of residue was at least 3-4 tons of dry matter/ha. The amount of residue required was less when tied ridges were used. Under traditional (hand-hoeing) soil prerparation methods, the systematic removal of crop residues leads to such low infiltration rates that grain yield response to fertilizer applications was very small or non-existent (IITA/SAFGRAD, 1983).

Drought stress

Alone or in combination, the following practices reduce the risk of drought stress.

Soil tillage. Tractor, oxen, donkey and hand-hoe tillage methods improve infiltration and soil water storage. Deep tillage was generally better than shallow tillage. The effect of soil tillage was only temporary and was not enough to ensure improved soil water infiltration rates throughout the growing season (Figs. 1, 2, 3).

Tied ridges. Evaluation of tied ridges in the Sudan Savanna of Burkina Faso was introduced by the IITA/SAFGRAD Maize Agronomy Program in 1979. Since then, tied ridges have been very effective in increasing infiltration and decreasing runoff losses. This is particularly true in those soils which have low infiltration rates due to surface sealing, crusting or compact subsoil layers, etc. The yield response to tied ridges has been more consistent in the Sudan than in the Northern Guinea Savanna (Figs. 4 and 5, Table 3).

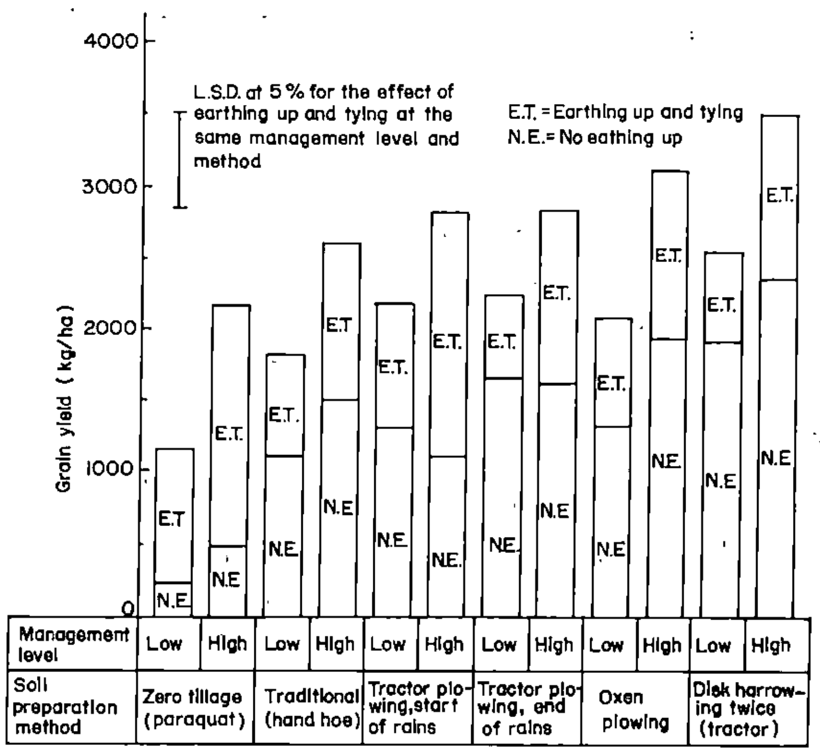


Figure 1 The effect of different soil preparation methods and of earthing up and tying on the grain yield of maize. Kamboinsé, 1981.

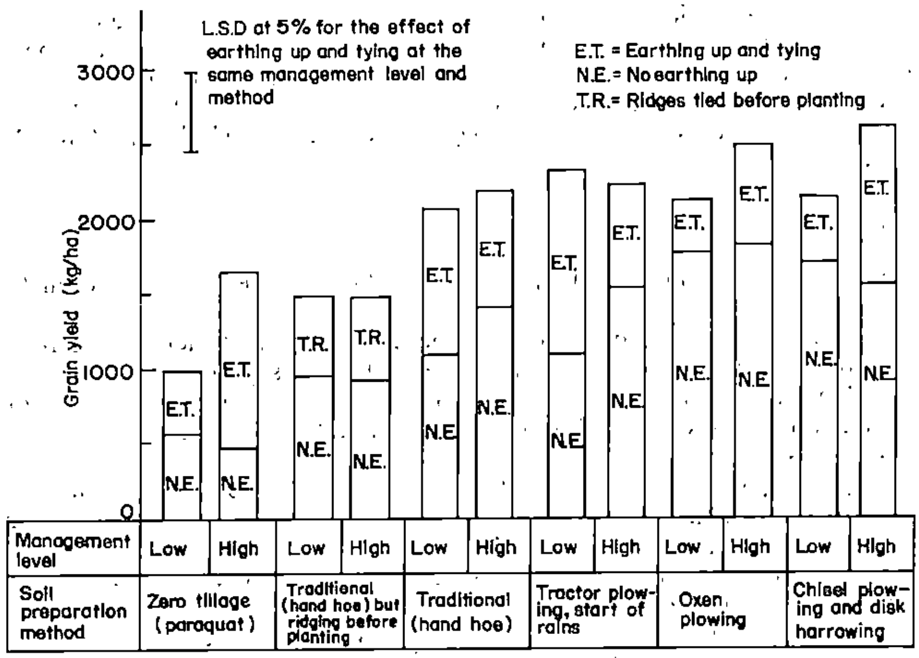


Figure 2 The effect of soil preparation methods and tied earthing up on the grain yield of maize. Saria, 1981.

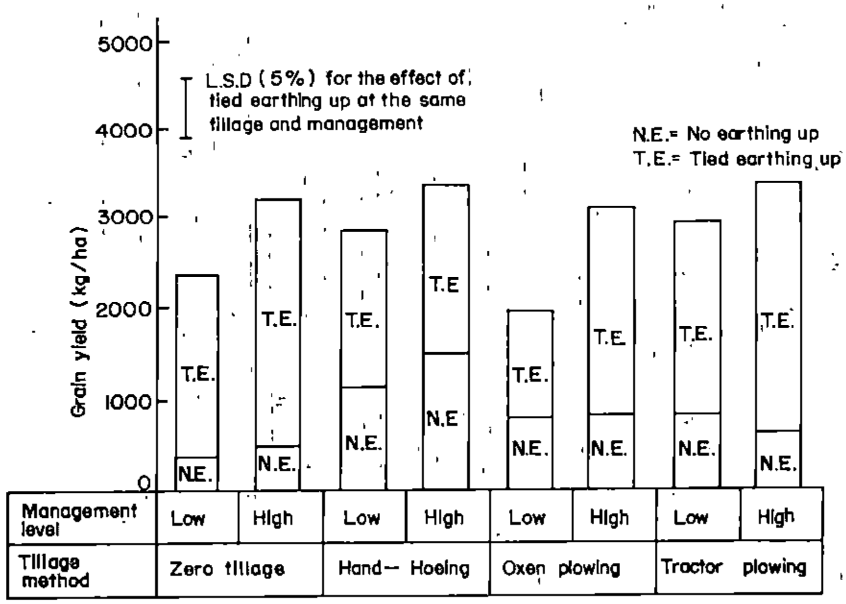


Figure 3 The effect of tillage methods and tied earthing up on the grain yield of maize. Kamboinsé, 1983.

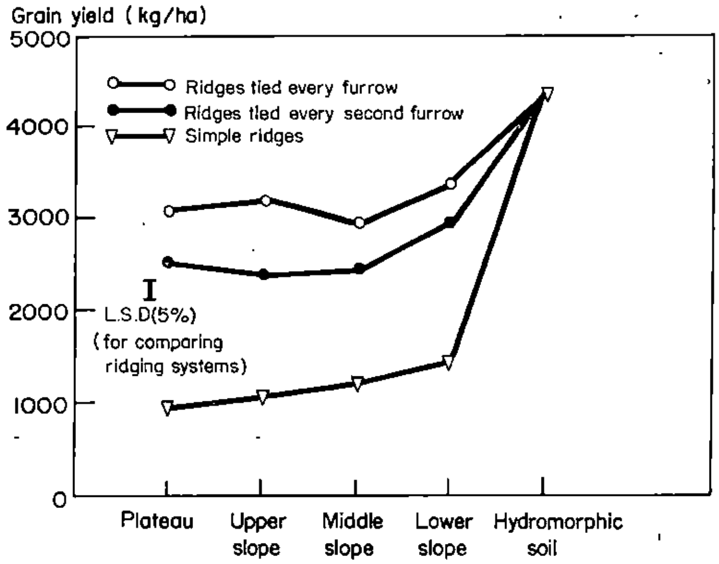


Figure 4 The effect of crop position along the toposequence and of tied ridges on the grain yield of maize. Kamboinsé, 1981.

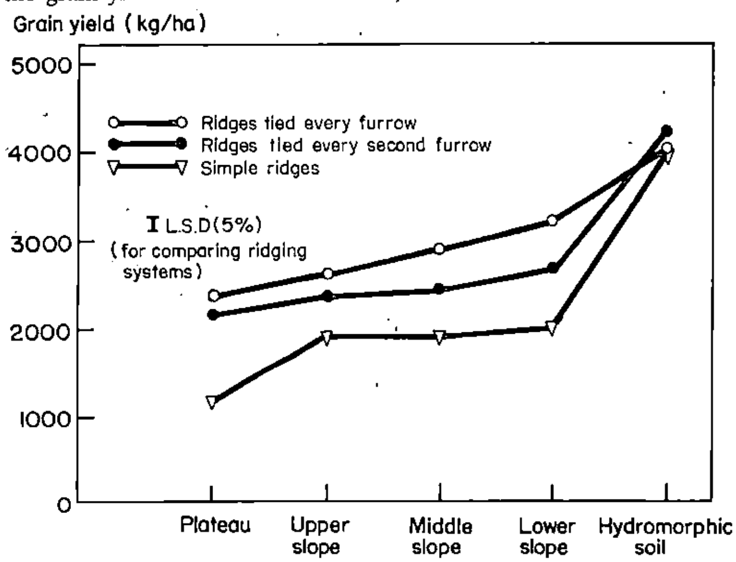


Figure 5 The effect of crop position along the toposequence and of tied ridges on the grain yield of maize. Kamboinsé, 1983. Average of two planting dates.

Tied ridges can be estalished at or before planting, or at the time of earthing (hilling) up. If farmers do not have the means to make tied ridges before planting, they may plant on the flat. Later, when plants reach a minimum height of about 25 cm and when labor is less of a constraint, they can earth up and tie their ridges. Long term trials have also shown that it is profitable for farmers to plant directly on old tied ridges, without any prior soil preparation except weeding (Table 4). The latter is a more viable option in the Sudan than in the Northern Guinea Savanna because the longer dry season lessens the problem of weed control.

No yield response to tied ridges was found in the Weakly Ferrallitic Soils at

Table 3 The effect of crop position along the toposequence and of ridge tying on the grain yield of maize (kg/ha, at zero percent moisture) at Kamboinsé, 1982. (Means of two planting dates).

Position	Ridging system		
	Simple ridges	Ridge tying every second furrow	All ridges tied
Plateau	480	1150	1240
Upper slope	1240	1710	2260
Midslope	1030	1770	1870
Lower slope	830	1470	2330
Bottom land	3190	2580	3060
Mean	1350	1740	2150

L.S.D. (5%) for comparing ridging systems: 202
L.S.D. (5%) for comparing ridging systems at each position: 452

Farako-Bâ. These are typical forest zone soils, however, which are not common in the West African Savanna. At Saria, only on poorly or imperfectly drained lower slope soils were there negative effects in most years of tied ridging on maize growth and yield (IITA/SAFGRAD, 1984).

The grain yield increase obtained on-station using tied ridges can be as high as 2000 kg/ha when soil fertility is not a yield limiting factor. Yield increases of 1 ton/ha are common. On-farm tests have given yield increases of up to 500 kg/ha. The labor cost of making tied ridges by hand was estimated at 27 man-days/ha or 10.800 CFA/ha (opportunity cost of labor at 50 CFA/hour). At a maize price of 90 CFA/kg such labor costs equal 120 kg maize/ha, which is only a fraction of the potential yield increase.

Table 4 The effect of earthing up and of ridge tying on the grain yield of maize (kg/ha at zero percent moisture) at Kamboinsé, 1981 and 1982.

Earthing-up system*	Management level			
	Low		High	
	1981	1982	1981	1982
1. No earthing up	1040	1270	1480	2270
2. Earthing up	990	1080	1470	2690
3. Earthing up and tying of every second furrow	1840	2560	2540	3100
4. Earthing up and tying of all furrows	2040	2230	3280	3240
L.S.D. (5%)	588	677	588	677

* The soil is prepared following the traditional hand-hoeing but the tied ridges are kept from year to year.

Although tied ridges can be made by hand and still be economically profitable, a mechanical device adapted to animal traction has made tied ridging even more attractive. Two versions of such a device have been developed by the IITA/SAFGRAD Maize Agronomy Program (Fig. 6); one designed for donkey and the second for oxen traction. (Wright and Rodriguez, 1985a, 1985b). The donkey model has shovels which are 16 cm wide at the outer edge, widening to 49 cm at the center. It weighs 11 kg and costs about 14,000 CFA to produce. The same parameters for the oxen model are 20 cm, 55 cm, 17 kg, and roughly 16,000 CFA. In 1985, more than 130 units of both ridge-tiers were built and widely distributed to farmers and cooperators in Burkina. Evaluation of these tests has not yet been completed, and additional design improvements are underway. Preliminary results indicate good acceptance of the donkey model by farmers (Nagy et al, 1986).

Shallow ditches. Digging shallow ditches or small holes between the maize rows also increased soil water retention and decreased runoff. Experiments have shown large yield increases due to digging holes approximately 40 cm long × 20 cm wide × 10 cm deep (Table 5). Such yield increases were usually smaller than those obtained by making tied ridges, due to the larger volume water contained by the latter. If the farmer plants on the flat, he can dig small holes between rows any time after planting; whereas tied ridges can be established only after the plants reach a minimum height, usually 25 or more days after planting.

It has been concluded that the risk of drought stress can be reduced by any sort of small hole, catchment, basin, or terrain irregularity that slows down water runoff and conserves rainfall.

Cultivations (scarifications) for breaking a sealed soil surface or crust. Crusting and/or surface sealing are soil characteristics frequently encountered in Burkina Faso. The results are poorer soil aeration and reduced

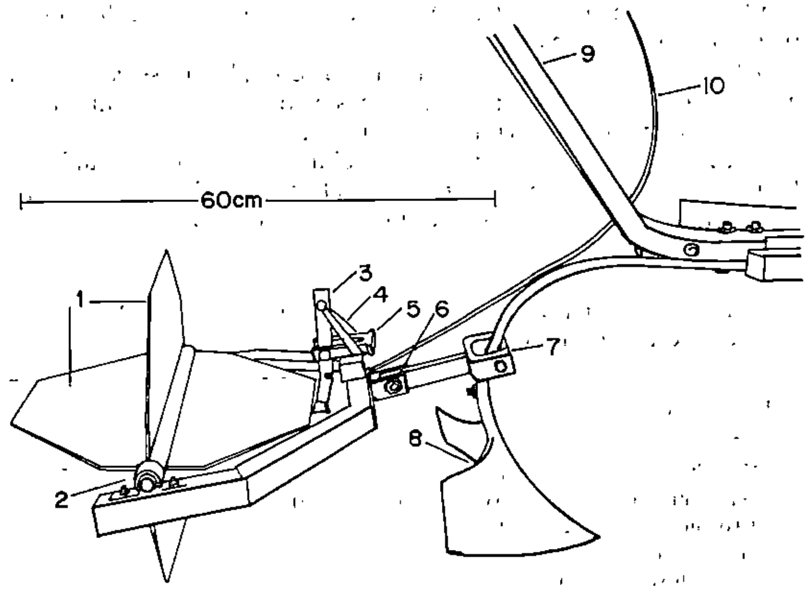
Table 5 Cultivation (scarification) trial. Kamboinsé, 1981, 1982. Grain yield (kg/ha, at zero percent moisture).

Cultivation System	1981	1982
1. No cultivation after planting	685	806
2. One cultivation at 4 WAP (weeks after planting)	844	–
3. Two cultivations at 2 and 4 WAP	1151	718
4. Three cultivations at 2, 4 and 6 WAP	1178	–
5. Four cultivations at 14, 24, 34 and 44 DAP	1634	933
6. Four cultivations at 14, 28, 42, and 60 DAP	–	898
7. Two cultivations at 2 and 4 WAP. The second cultivation is simultaneous with the digging of small basins or holes ($40 \times 20 \times 10$ cm^3) between the maize rows but without earthing up	2470	1292
8. Two cultivations at 2 and 4 WAP. The second cultivation is simultaneous with earthing up and tying of the ridges thus formed	–	1418
Mean	1327	1011
C.V.	27.1	25.8
L.S.D. (5%)	475	344

water infiltration leading to a greater risk of drought stress. Even in the absence of weeds, cultivations after planting led to improved grain yields (Table 5). In general, the greater the number of cultivations, the higher the yield. It was also shown that cultivations were not as effective as either digging small holes or as ridge tying in increasing maize yields. Moreover, cultivations can cause root prunning and/or exposure of moist soil to dessication, thereby depressing yields.

Planting of maize on lower slope and hydromorphic soils. There was a very marked toposequence effect on maize grain yield. Yields were lowest on plateau soils and increased toward lower slopes and hydromorphic soils. The difference in grain yield was two to five fold, even when improved soil and water management practices such as tillage, tied ridges and fertilizer were used (Figs. 4 and 5, Table 3).

Use of residues as a mulch. The effect of crop residues has already been discussed under soil compaction. Maize crop residues can have a very significant effect on maize grain yield (Table 6). Although farmers need crop residues for fuel, fodder and construction material, the current practice of systematic crop removal from the field is counter-productive in the long run and is one of the major factors responsible for the current degradation of the soil resource base.



(1) Shovels
(2) Axel Bearing (Pipe)
(3) Latch Lever
(4) Rubber Band (Inner Tube Strip)
(5) Latch Adjuster (for correct angle and to compensate for wear in bearings, shovels and latch).
(6) Shovel angle Adjusting Bolt
(7) Coupler
(8) 30cm Ridger that allows soil to flow over the top.
(9) Handles of "houe Manga" (FAO donkey weeder)
(10) Bicycle cable to Brake Lever

Figure 6 The IITA/SAFGRAD Trap ridge-tier (Donkey Version)

Table 6 Residue management trial, Kambóinsé, 1982. Grain yield (kg/ha, at zero percent moisture).

Management level*	Ridging system**	Residue management[a]** 1 No residue	2 Residue	3 Residue × 2	Mean
Low	Flat	990	800	1530	1110
	Tied ridges	1910	2040	2350	2100
	Mean	1450	1420	1940	1600
High	Flat	1020	2110	2690	1940
	Tied ridges	1460	2780	2980	2410
	Mean	1240	2450	2830	2170
Ridging System	Flat	1000	1460	2110	1520
	Tied ridges	1680	2410	2660	2250
Mean		1340	1940	2390	1890

Management × Residue**	C.V.	Main plot	27.0
Management × Ridging*		Subplot	27.6
Residue × Ridging[ns]		Sub-sub-plot	23.0
Management × Residue × Ridging[ns]			

*, **: Significant at 5% and 1% levels
[ns]: Non significant
L.S.D.'s at 5%

Management levels	366
Residue managements	351
Residue managements at same or different ridging	451
Ridging systems	231
Ridging systems at same management level	327
Ridging systems at same residue management	401
Ridging systems at same residue management and management level	567
Residue management at same management level and same or different ridgings	520

[a] Residue managements
1: Crop residue removed
2: Crop residue left in situ
3: Crop residue amount doubled

The crop residue left in situ was 2.5 and 4.0 ton D.M./ha under low and high management levels respectively.

Table 7 Planting date trial. Farako-Bâ (Northern Guinea Savanna), 1983. Maize grain yield (kg/ha, at zero percent moisture).

Management level**	Variety**	Planting date**				Mean
		June 22	July 8	July 22	August 7	
M1	SAFITA-2	1655	1195	855	190	970
	SAFITA-102	1530	1175	515	40	815
	Mean	1595	1185	685	115	895
M2	SAFITA-2	3025	2445	965	210	1660
	SAFITA-102	3040	1940	350	10	1335
	Mean	3030	2190	655	110	1500
Variety	SAFITA-2	2340	1820	910	200	1315
	SAFITA-102	2285	1560	4430	25	1075
	Mean	2310	1690	670	110	1195

Management × Date**	C.V. %	Main plot	20.2
Management × Variety^{ns}		Sub-plot	27.0
Date × Variety*		Subsub-plot	17.1
Management × Date × Variety ^{ns}			

*, **: Significant 5 and 1%
^{ns}: Non significant
L.S.D.'s at 5%

Management levels	150
Dates	211
Varieties	93
Varieties at same Management	132
Varieties at same Date	186
Varieties at same Date and Management	264
Dates at same Management and same or different Variety	249

Use of varieties whose maturity fits the length of the growing cycle. Under "average" rainfall conditions, varieties of the following maturities should be used in simple maize monocropping systems:

Sudan Savanna: early varieties (82-95 days). Northern Guinea Savanna: intermediate maturity varieties (96-110 days).

There is a demonstrated need to develop extra-early maize varieties (less than 82 days to maturity) to be used in the Sudan Savanna in those years when maize can not be planted as soon as it should or has to be replanted when the remaining part of the growing season is too short for planting an early variety.

Appropriate planting dates. When rainfall conditions permit, it appears that the optimum planting dates for maize are June 15-30 in the Sudan Savanna and June 1-20 in the Northern Guinea Savanna. Nevertheless, given the high variability in the rainfall distribution pattern from year to year and the erratic occurrence of dry spells during the growing season, there were years when the highest maize grain yields were obtained when the planting date was earlier or later than the average optimum given above (Table 7).

Other agronomic studies

Planting depth. In experiments where there was over-planting and thinning to one plant/hill, deep planting (8-10 cm depth) gave the same grain yield as shallow planting (3-5 cm). Nevertheless, deep planting reduced field germination and could lead to decreased stands and lower yields under farmers' conditions, where over-planting and thinning don't normally occur (IITA/SAFGRAD, 1982).

Seedbed. Experiments in the Sudan and Northern Guinea Savannas showed no differences in maize grain yield between planting on the flat and planting on simple (non-tied) ridges (Rodriguez, 1980; IITA/SAFGRAD, 1982 and 1985).

Earthing up. In the absence of tied ridges, earthing up had no effect on maize grain yield as opposed to planting on the flat without earthing up (IITA/SAFGRAD, 1982 and 1985).

Plants/hill. Experiments in the Sudan Savanna showed that, at the same plant density, there were no grain yield differences between or or two plants per hill. When the number of plants/hill increased to 3 or 4, grain yields decreased (IITA/SAFGRAD, 1985).

Seed size. There is a direct effect of seed size on field germination and seedling vigor, but its effect on yield has not been consistent over the years. A small seed size leads to lower field germination rates and can result in lower maize grain yields (IITA/SAFGRAD, 1985).

Plant density. The optimum plant density for maximum grain yield changes with soil fertility, planting date and number of days to maturity. When soil fertility is not a major limiting factor and the planting date is appropriate, optimum densities are similar to those found in more humid zones: Intermediate varieties: 50,000 to 65,000 plants/ha. Early varieties: 65,000 to 90,000plants/ha (IITA/SAFGRAD, 1980; IITA/SAFGRAD, 1985). These optimum densities can be reduced by 20-30% with only a small (less than 10%) effect on grain yield. By using densities which are 20-30% below those which give the highest grain yields, the small farmer can decrease his planting and harvesting costs. Such sub-optimal densities can also reduce the risk of crop failure if grain filling occurs during a very severe drought.

Optimum densities decrease as soil fertility becomes a yield limiting factor. Under very low fertility, the optimum density for intermediate maturity varieties is about 25,000 plants/ha. The effect of planting date on stand density becomes very important when most of the grain filling period occurs under conditions of very low soil moisture. In this case, the optimum density should be drastically reduced to 20,000-25,000 plants/ha.

Thinning date. Results showed no effect of thinning date between 12 and 25 days after planting on maize grain yield. Although thinning is not a practice normally followed by the maize farmer, over-planting and thinning late (20 days after planting) can increase a researchers' chance of obtaining desired stands and higher within-plot uniformity.

Spatial arrangement. There were no differences in maize grain yield between row spacings of 37.5 cm and 75 cm. At a row spacing of 112.5 cm, yields were the same as at 75 cm with a density of 40,000 plants/ha, but lower yields were obtained at a density of 67,000 plants/ha.

Potassium fertilizer. Short term studies showed no grain yield increase due to the application of potassium fertilizers.

Zinc deficiencies. In some years, zinc deficiency symptoms have been observed in the Sudan Savanna, but no grain yield response to zinc application was found. Foliar sprays of zinc sulfate were effective in correcting the deficiency symptoms.

Effect of Furadan (Carbofuran). Soil applications of Furadan 5G at or after planting and/or during the crop cycle often gave grain yield increases, sometimes as high as 1 ton/ha. The positive effect of Furadan is due mostly to termite control in the Sudan Savanna, whereas it helps control termites, stem borers, maize streak virus and some soil insects in the Northern Guinea Savanna (IITA/SAFGRAD, 1985).

Local varieties. Most of the early (82-95 day) local varieties in the Sudan Savanna showed good yield potential (4-5 ton/ha) when properly managed. Some had good agronomic characteristics while others were highly susceptible to lodging. Although foliar diseases are not a major problem in the Sudan Savanna, all local varieties appear to be highly susceptible to them.

Genotype × Management Interactions. Many trials were conducted to compare varieties under low and high fertility and/or drought stress. In general, local varieties did not perform better than improved varieties of the same maturity.

Conclusions

Although the erratic rainfall distribution patterns characteristic of the WASAT are a constraint for increased maize production in the area, research results indicate that several management alternatives can substantially reduce water losses by runoff, improve crop use of the available rainfall, reduce the risk of drought stress and increase maize grain and total dry matter yields. Given that agronomic practices alone (without the use of irrigation) cannot completely eliminate the risk of drought stress, there is a clear justification for breeding programs geared towards increasing maize genetic resistance to drought.

The common occurence in the WASAT of both low soil fertility conditions and pedoclimatic factors conducive to drought stress make it necessary to address both problems simultaneously. Improving soil fertility alone or soil-water management alone will be of limited value in such cases. On the other hand, if done together, the return on inputs and labor will be enhanced.

Rainfall variability from year to year is such that there are bound to be good and bad years for crop production. In the latter case, low yields are to be expected even if improved soil-water management technologies are utilized. It seems logical to think that the food deficit in those bad years should be compensated, at least partially, by overproduction in the good years which can happen only if fertility is not a serious yield limiting factor. In this respect, improving soil fertility for phosphorus seems to be economic, given the low losses of P from the soil system and the high residual P responses. Far more research is needed to determine the fate of applied soil nitrogen, and the most efficient methods of N application or of improving the soil N status in the WASAT. There are, however, reasons to think that N leaching losses in the Alfisols of the Sudan Savanna could be relatively small.

In the future the importance of maize in the Sudan Savanna is bound to increase, but it is difficult to assess to what degree. Total rainfall (600-900 mm in 3-4 months), not taking into account its distribution, is certainly enough for a 80-90 day crop if a daily potential evapotranspiration of 4-6 mm/day is considered. It seems that farmers' ability to solve both the fertility problems and to use improved soil-water management practices both of which are often required, will dictate the extent to which maize will become a more important cereal in this ecology.

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40 Labour et amenagement du sol en vue d'accroître le rendement des cultures vivrières dans les régions semi-arides d'Afrique sub saharienne

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Dans les régions semi-arides d'Afrique sub-saharienne, la croissance des principales cultures vivrières est rendue très difficile par les conditions pédoclimatiques souvent défavorables.

Les sols ont de mauvaises propriétés physiques qui limitent le développement des plantes; ils sont, de plus, sensibles à la dégradation; les pluies trop rares ou quelquefois trop abondantes qui tombent avec une très forte intensité, provoquant d'importants phénomènes d'érosion et de ruissellement.

Le climat se caractérise en particulier par son irrégularité et le problème de l'alimentation hydrique des cultures se pose de manière préoccupante.

Il apparaît très nettement que l'un des meilleurs moyens de lever ces contraintes était d'utiliser de bonnes techniques de travail du sol au niveau de la parcelle et de les placer dans le cadre d'un paysage rural aménagé pour permettre une efficacité maximale de la pluviométrie.

Nous allons ici examiner un certain nombre de ces techniques associant travail du sol et aménagement en mettant en valeur les avantages et inconvénients de chacune d'entre elles. Il n'y a pas de solution miracle passe-partout, il faut s'adapter en fonction du contexte pédoclimatique et des possibilités du cultivateur.

Caractéristiques principales du climat et des sols de la zone semi-aride d'Afrique sub-sahariene

Le Climat

Le climat de la zone tropicale semi-aride d'Afrique sub-saharienne se caractérise par l'opposition entre une saison des pluies dont la durée peut varier de 2 à 6 mois et une saison entièrement sèche.

La pluviométrie annuelle varie entre 200 et 1300 mm. En Afrique de l'Ouest les isohyètes sont grossièrement parallèles à l'équateur et la pluviométrie présente un fort gradient d'augmentation en allant du Nord vers le Sud.

L'extrême irrégularité des précipitations fait que la saison des pluies est souvent une succession de périodes pluvieuses et de périodes sèches, ces dernières devenant de plus en plus fréquentes à mesure que l'on va vers les pluviométries les plus basses.

La zone est soumise à une très forte demande évaporative: l'ETP annuelle est comprise en gros entre 2200 mm au Nord et 1600 mm au Sud.

L'eau est donc le premier facteur limitant; mais comme cette pluviométrie est concentrée dans une période limitée avec un pic en milieu de saison des pluies, il y a pratiquement toujours une certaine quantité d'eau qui ruisselle à la surface. Par ailleurs les pluies se présentant souvent comme des orages très intenses, elles peuvent aussi créer des phénomènes d'engorgement superficiel. Durant la saison des pluies il y a alternance entre 2 extrêmes: déficit et excès d'eau.

Deux autres caractéristiques ont une certaine importance pour expliquer le comportement des sols

- l'absence de gel: les températres descendent rarement au-dessous de 10°
- la très haute intensité des pluies et leur pouvoir érosif. C'est l'aggressivité du climat qui est à l'origine de la forte érosion hydrique.

Les Sols

La majorité des sols exondés des régions semi-arides sub-sahariennes présentent des caractères communs qui conditionnent les propriétés physiques des sols

- les horizons supérieurs sont sableux ou sablo-argileux (taux d'argile en général inférieur à 20%)
- la fraction argileuse est constituée principalement de kaolinite et d'hydroxydes de fer amorphes, minéraux peu gonflants

Les phénomènes de gonflement et de retrait sont donc rares et il n'y a pas de régénération de la structure. Ces sols sont structurellement inertes.

Etant donné ces caractéristiques, les principales propriétés des horizons superficiels peuvent être ainsi énumérées

- très faible structure fragmentaire (si elle existe)
- porosité plutôt basse (40 à 45%) considérée comme limite pour le développement du système racinaire des plantes
- très faible porosité structurale (porosité liée à la pénétration racinaire et à la circulation de l'eau)
- forte tendance à la compaction et au durcissement pendant la saison sèche
- capacité d'infiltration variables en fonction du sol et du matériau d'origine
- réserve en eau utile plutôt basse
- susceptibilité à l'érosion faible à moyenne

Ces propriétés physiques sont très défavorables à la croissance des espèces cultivées et en particulier la faible porosité. On a en effet mis en évidence de nombreuses corrélations entre la porosité des horizons superficiels et la densité racinaire des différentes cultures mais aussi entre cette porosité et les rendements des mêmes cultures.

On a pu observer dans les conditions naturelles que les jachères de courte durée ont un système racinaire qui ne colonise que les dix premiers centimètres. Au fur et à mesure que la durée de la jachère augmente (à partir de 3 à 4 ans) des espèces pérennes à enracinement puissant s'ins tallent: on peut alors observer des profils véritablement colonisés en profondeur mais souvent de manière discontinue en fonction des éspècs végetales qui composent la jachère.

On ne peut donc compter ni sur les conditions naturelles ni sur la présence du système racinaire des plantes annuelles pour créer une structure meilleure et augmenter la porosité. Il est donc nécessaire d'avoir recours au travail du sol.

Par contre les vertisols où les sols similaires dont le taux d'argile est supérieur à 20% et qui contiennent des minéraux gonflants dans la fraction argileuse (montmorillonite) sont généralement considérés comme structurellement actifs. Ils ont souvent une bonne structure, une porosité satisfaisante et les racines des plantes sont capables d'améliorer la structure du sol. Le travail du sol peut ne pas être nécessaire, le facteur limitant pour la croissance des plantes est le plus souvent l'infiltration insuffisante et l'engorgement des horizons profonds, spécialement dans les vertisols dégradés.

Les differentes techniques de travail du sol

Nous nous intéresserons plus particulièrement aux sols sableux et sablo-argileux les plus répandus dans la zone; mais nous traiterons à la fin du problème particulier des sols plus argileux.

Compte tenu du contexte climatique et du problème essentiel que constitue la lutte contre la sécheresse, nous mettrons l'accent sur les effets des techniques de travail du sol en vue d'une utilisation maximale de l'eau de pluie.

De ce point de vue les interventions mécaniques sur le sol doivent avoir trois objectifs:

- Emmagasiner l'eau de pluie et pour cela faciliter son infiltration aux détriments du ruissellement
- Faciliter l'utilisation de l'eau strockée en favorisant la croissante racinaire en profondeur
- Conserver l'eau emmagasinée en réduisant l'évaporation et en limitant si possible les percolations en profondeur.

Le labour à plat

Le labour consiste à prendre la terre, à la briser et à la retouner en la divisant plus ou moins finement en fonction de son humidité. Il se réalise avec une charrue à soc en culture attelée, charrue à soc ou à disques en culture motorisée. Cette action mécanique est préponderante: elle amène un bouleversement complet de la structure du sol dans l'horizon travaillé.

Rappel des effets du labour sur le sol

La structure du sol: conséquences sur l'enracinement des cultures

Le labour augmente la porosité totale des horizons superficiels quelles que soient les conditions de réalisation. Il crée une fissuration qui n'existe souvent pas dans les conditions naturelles.

Cet accroissement de porosité, qui peut paraître limité (10 à 20% a des conséquences importantes en particulier sur le développement racinaire des plantes annuelles cultivées. Ce sont toutes les caractéristiques du système racinaire qui sont modifiées.

- Vitesse de progression du front racinaire
- Profondeur maximale et longueur totale
- Densité racinaire en profondeur
- Ecart moyen entre deux racines

Le régime hydrique des sols

C'est l'un des effets les plus bénéfiques du labour en zone tropicale sèche. Il accroit l'infiltration et diminue le ruissellement

- en augmentant la porosité des horizons de surface
- en créant des obstacles à la circulation partielle ou totale de l'eau à la surface du sol, ce qui l'oblige à pénétrer: structure superficielle motteuse, modification du modelé du terrain.

L'efficacité propre du labour est surtout sensible en début de cycle.

- Il permet une meilleure utilisation par la plante de l'eau stokée: grâce à une meilleure exploitation du sol par les racines, le réservoir d'eau mis á la disposition de la plante est plus important.
- Réalisé en fin de saison des pluies il permet de réduire l'évaporation pendant la saison sèche car il rompt le front capillaire et supprime toute végétation adventice. Des reports d'eau d'une année sur l'autre sont aussi possibles: ils peuvent être fort utiles en cas de sécheresse ou début de cycle (Sénégal 1972).

La lutte contre l'érosion

Réalisé dans de bonnes conditions, c'est-à-dire à vitesse lente avec des charrues à soc travaillant dans le sens perpendiculaire à la pente en n'émiettant pas le sol, le labour peut être un excellent moyen de lutte contre l'érosion

+ érosion éolienne: lorsque le sol est labouré le vent peut difficilement soulever les mottes qui offrent plus de prise qu'un sol pulvérulent
+ érosion hydrique: le ruissellement étant diminué la quantité de terre érodée décroit en proportion.

La matière organique et la vie mirobienne du sol

Le labour peut augmenter de manière significative la minéralisation de l'azote pendant la saison des pluies ce qui augmente le rendement des céréales.

Il peut aussi avoir des effets importants sur l'activté symbiotique des rhizobiums en particulier en culture arachidière, probablement en raison d'une meilleure aération du sol.

Effets du labour sur le rendement des cultures

On dispose d'un très grand nombre de données obtenues en Afrique de l'Ouest francophone. Elles proviennent soit de parcelles expérimentales, soit de champs de prévulgarisation d'une superficie égale ou supérieure à 400 m2. Dans le tableau 1 on a récapitulé les moyennes des rendements obtenus essentiellement dans 2 pays, le Sénégal et le Burkina Faso. Certaines données sont anciennes et datent des anées 60, d'autres sont lus récentes (1985). Nous avons voulu donner un échantillonnage des reponses possibles en fonction de la nature de la plante cultivée.

Il s'agit d'effets du labour seul, sans tenir compte des enfouissements de matière organique qui peuvent modifier les pourcentages dans un sens ou dans l'autre en fonction de la nature de la matière organique.

Les céréales sont très sensibles aux effets du labour qui vont en augmentant lorsqu'on passe du mil au sorgho puis au maïs et au riz pluvial.

Tableau 1 Effets directs du labour à plat sur le rendement des principales cultures

	Nombre de résultats annuels	Rendement Témoin traditionnel kg/ha	Rendement Labour kg/ha	Gain dû au labour %
Mil (grain)	57	1392	1642	+ 18
Sorgho (grain)	87	1653	2109	+ 28
Maïs (grain)	58	2008	3104	+ 55
Riz pluvial paddy	29	1360	2329	+ 71
Cotonnier (coton graine)	30	1272	1520	+ 19
Arachide (gousses)	79	1084	1299	+ 20

Cela dépend beaucoup de la rusticité de l'espèce et de son adaptation à l'aridité du climat.

Pour l'arachide les augmentations de rendement sont d'autant plus marquées que les sols sont plus sableux. Ceci peut s'expliquer par l'action du labour sur la fixation symbiotique de l'azote.

Le cotonnier réagit bien au labour lorsque les conditions naturelles de croissance du pivot racinaire sont mauvaises.

On a aussi enregistré des effets résiduels du labour qui peuvent être relativement importants et dépendent le plus souvent de la rotation. Les céréales conservent mieux, grâce à leur enracinement fasciculé, la macrostructure créée dans le sol alors qu'après arachide il ne reste souvent plus rien. Cela permet donc d'envisager une périodicité du labour tous les deux ou trois ans et donc la répartition du travail sur l'ensemble de l'exploitation.

Enfin, le labour a un effet très marqué sur la croissance des adventices. On a montré qu'un labour correctement effectué permettait de réduire le nombre des sarclages de manière significative et de toute manière de différer la date de la première intervention ce qui est important pour le calendrier cultural de l'exploitation.

Conclusion

L'ensemble des nombreux résultats obtenus montrent qu'en moyenne le labour joue un rôle important dans l'augmentation de la productivité des sols et donc du rendement des cultures en zone tropicale semi-aride. Cependant les effets peuvent être plus ou moins marqués car ils sont sous la dépendance de nombreux facteurs et en particulier

- du sol
- du climat et de la végétation
- de la plante cultivée
- du passé cultural de la parcelle.

Il ne faut donc pas s'étonner d'une certaine variabilité des résultats surtout lorsqu'on les met en application dans le milieu paysan où les conditions de realisations sont loin d'être parfaites.

Les travaux de préparation du sol aux dents

Le travail du sol aux dents permet de travailler le sol sans le retourner. Il a pour but, en particulier, de faire pénétrer l'eau de pluie sans bouleverser la surface du sol. Il peut se présenter sous différentes formes.

– *Scarifiage en sec* réalisé avec différents types de dents et qui permet d'éclater le sol (canadien à dents souples, pic fouilleur, pointe diamant dur étançon rigide . . . etc.). Réalisé en culture attelée bovine, il est obligatoirement limité en largeur et en profondeur par la force de traction et il reste le plus souvent très localisé et superficiel.

Les augmentations de rendement obtenues sont très irrégulières et dépendent beaucoup du volume de sol réellement touché par les modifications de structure. En expérimentations elles varient de 0 à 15%

– *Passage de dents en humide*: le travail est plus profond et couvre plus de surface. L'utilisation de pièces dites "pattes d'oies" peut être très efficace, car elles produisent un foisonnement sur les 10 à 12 cm d'horizons superficiels avec augmentation de la porosité. Mais le passage de dents doit être réalisé après le début des pluies et il entre ainsi en concurrence avec le semis. Les augmentations de rendements varient de 0 à 30% (alors que dans les mêmes conditions on obtient 20 à 50% avec le labour)

– *Le Chisel* ne peut être utilisé qu'en culture motorisée. En sec sa profondeur de travail est le plus souvent limitée en raison du phénomène de durcissement des sols; mais la surface travaillée peut être importante. Lorsque le chisel est adapté et le travail réalisé dans de bonnes conditions (éclatement satisfaisant) les plus values enregistrées peuvent atteindre 27% sur maïs.

– *Le Sous-solage* éclate le sol sur une plus grande profondeur, mais la force de traction nécessaire est très élevée. Cependant les passages d'engins étant espacés de 1 à 1,5 m cela réduit les temps de travaux. Il est plus rapide de passer en sec une sous-soleuse que de labourer au tracteur 1 hectare en sol humide. L'efficacité du sous-solage dépend beaucoup de la nature du sol: s'il est trop sableux, l'éclatement est insuffisant et les modifications de structure ont tendance à disparaître rapidement. Si le taux d'argile est suffisant, l'effet peut durer au moins deux ans.

A titre d'exemple on citera ici les chiffres obtenus à Gampéla au Burkina Faso sur des sols ferrugineux tropicaux comportant entre 15 et 30% d'Argile + limon dans les 40 premiers centimètres.

Tableau 2 Effets des traitements du travail du sol à Gampéla Rendements kg/ha

	Sorgho 1981	Arachide 1983	Sorgho 1984
Témoin	950	1284	523
Chisel	1020	1186	652
Chisel/sous-solage de l'année précédente	1200	1659	1050
Sous-solage de l'année	1390	1567	1841
Labour charrue à soc culture motorisée	1340	2000	1020

L'efficacité du travail aux dents est très variable.

– Du point de vue de l'économie de l'eau, plus le travail est profond, plus, les passages sont rapprochés, meilleure est l'infiltration. Un sous-solage

peut être très efficace, un simple scarifiage reste très aléatoire. L'intérêt de ces techniques est, qu'etant réalisées pendant la période sèche, elles évitent de retarder le semis et permettent de stocker les premières pluies.
- L'action sur l'enracinement est limitée à la zone travaillée. Si les lignes de semis se retrouvent sur le passage des dents il y a pénétration préférentielle et une efficacité certaine. Entre les dents il n'ya aucun effet visible, la pénétration racinaire est donc très irrégulière.
- Le travail aux dents, seul ne joue aucun rôle dans la lutte contre l'evaporation. Par contre il peut être efficacement combiné au mulch des résidus culturaux.

Labour en billons et buttage

Le labour en billons consiste à effectuer des levées de terre rectilignes régulièrement espacées avec une charrue, un corps butteur ou un instrument de culture manuel. La terre est prise dans l'interligne et rapportée sur une partie non travaillée. Les plantes sont semées au sommet ou sur le flanc des billons.

On s'accorde à reconnaître à la culture en billons un certain nombre d'avantages par rapport au labour à plat:

- *Meilleure infiltration de l'eau dans le sol*: en effet le billon canalise l'eau de pluie, l'empêche de ruisseler pour en garder le maximum à la disposition de la plante. Mais cela n'est réellement possible.
  - que si les billons sont effectués perpendiculairement au sens de la pente
  - que si la pente qui existe dans l'interligne est très faible. Dans le cas contraire l'eau s'écoule plus vite.

Si les conditions précédentes sont réalisées, l'eau ne sera véri tablement disponible pour la plante que si la texture du sol le permet et l'enracinement des cultures est assez développé.

Meilleure protection contre l'érosion et le ruisselement

Il est de fait que des billons qui suivent exactement les courbes de niveau entravent efficacement le ruissellement et diminuent donc jusqu'à les annuler les pertes en terre, comme cela a pu être mesuré sur de nombreux dispositifs expérimentaux (Sénégal, Burkina Faso, Côte d'Ivoire). Mais la réalisation de dispositifs de billons en courbes de niveau sur de vastes superficies est très difficile. Il y a toujours un ou plusieurs points faibles dans le dispositif où l'eau s'accumulant derrière un billon finira par le faire céder, perçant tous les billons qui se trouvent en aval et pouvant entrainer tout le dispositif.

Il ne faut pas aussi oublier de parler de la dégradation qui se produit entre 2 billons: sables et argiles sont entrainés et viennent se déposer par lits successifs dans le fond du sillon. Il se développe alors une structure litée défavorable à l'enracinement.

Meilleure maîtrise de l'herbe

Dans les zones de l'Afrique de l'Ouest où l'on utilise traditionnellement cette technique, le travail est réalisé en culture manuelle et les semis sont en général retardés. Le billonnage est surtout utile pour maitriser les mauvaises herbes en début de cycle. En cultivant à plat le paysan n'arriverait pas à maîtriser l'herbe au moment du semis.

Dans les régions plus sèches et dans les sols sableux un autre inconvénient peut apparaître: les sols étant filtrants, l'eau ne reste pas dans le corps du billon. En cas de semis suivi d'une période de sécheresse la plante ne résiste pas et un resemis s'avère souvent nécessaire. Par contre s'il peut beaucoup en début de cycle, le système évite l'engorgement ce qui peut être un avantage pour certaines cultures.

Une expérimentation réalisée depuis 3 ans au Burkina Faso en plusieurs situations pédoclimatiques permet de se faire une plus juste idée des différences qui peuvent exister entre labour à plat et labour en billons. Elle porte uniquement sur les cultures de sorgho et de maïs.

Tableau 3 Comparaison labour à plat et labour en billon au Burkina Faso

	Nombre de résultats annuels	Témoin		Labour à plat		Labour en billons	
		kg/ha	%	kg/ha	%	kg/ha	%
Sorgho	20	730	100	1126	154	1090	149
Maïs	5	1893	100	2791	147	2323	123

D'une manière générale sur sorgho la différence entre les 2 techniques n'est jamais significative, le labour à plat étant en moyenne légèrement supérieur.

Par contre sur maïs la différence est plus importante. Cette culture est en effet sensible à l'effet du travail du sol sur l'enracinement et l'un des inconvénients du labour en billon est que l'on rapporte de la terre meuble sur une partie de sol non travaillée.

Comme nous le verrons plus loin, le fonctionnement du billon et les répercussions sur le rendement des cultures peuvent être considérablement améliorés par le cloisonnement.

Il consiste à ramener en cours de culture la terre de l'interligne sur les plantes cultivées. Le semis est fait à plat et ce n'est que lorsque la plante a atteint une certaine hauteur que l'on peut réaliser le buttage. C'est aussi une opération de lutte contre les mauvaises herbes qui peut être réalisée manuellement, en culture attelée bovine voire en culture motorisée en utilisant un corps butteur.

En ce qui concerne l'économie de l'eau, le but de l'opération est comparable à celui du billonnage: canaliser l'eau de pluie et faciliter son infiltration. Cependant les résultats obtenus varient en fonction de ce qui s'est passé avant le buttage, et de ce qui se passera après.

Si le semis a été fait après labour à plat, on peut espérer cumuler les effets du labour et celui du buttage. Cela a pu être mesuré au Burkina Faso.

Sur sorgho et cotonnier l'effet est intéressant. Sur maïs le buttage semble dépressif: cela pourrait être dû au sectionnement d'un certain nombre de racines de maïs au moment du buttage. La plante y serait très sensible.

Sur cotonnier d'autres résultats obtenus par l'IRCT semblent montrer que c'est une opération indispensable sans que l'on explique completement les effets

– effet sanitaire empêchant les pourritures à la base

Tableau 4 Effets du buttage sur les parcelles labourées

	Nombre de résultats annuels	Témoin		Labour à plat		Labour à plat + buttage	
		kg/ha	%	kg/ha	%	kg/ha	%
Sorgho	6	1071	100	1768	165	1985	178
Maïs	4	2183	100	3178	145	2883	132
Cotonnier	4	758	100	1085	143	1136	150

– emmagasinement de l'eau de pluie
– arrêt de l'érosion à condition qu'il soit fait dans le sens perpendiculaire à la pente

Pour les autres cultures on avance aussi deux autres arguments

– diminution de la verse
– moyen économique et rapide de lutte contre les mauvaise herbes

Comme le billonnage, le buttage voit son efficacité considérablement améliorée par le cloisonnement.

Les Billons cloisonnés

La technique du cloisonnement des billons consiste à effectuer des levées de terre à espacement régulier entre les billons de manière à éviter que l'eau ne circule et à créer ainsi des bassins de microcaptage. Tout ruissellement est pratiquement annulé au niveau de la parcelle. Toute l'eau de pluie qui arrive au sol est mise à la disposition de la plante dans la mesure où celle-ci peut l'utiliser grâce à un enracinement profond. Il faut aussi que le sol soit capable de la stocker et qu'elle ne percole pas rapidement pour disparaître dans les horizons inférieurs.

Cette technique peu utilisée traditionnellement en Afrique de l'Ouest est très répandue en Amérique du Sud. Elle a été très récemment étudiée en détail par plusieurs équipes de recherche au Burkina Faso par l'IITA-SAFGRAD, l'ICRISAT et l'IRAT-CIRAD en collaboration avec l'IBRAZ.

Toutes ces études ont permis de démontrer que l'efficacité du billon cloisonné était sous la dépendance de nombreux facteurs et en particulier

- l'écartement entre les cloisons: l'écartement le plus utilisé reste 1 mètre entre les cloisons, les plantes étant semées à écartement standard vulgarisé (le plus souvent 80 cm)
- la date de cloisonnement ou de réalisation du billon cloisonné un cloisonnement précoce parait préferable dans les régions Nord à faible pluviométrie.

Lorsqu'on descend vers le Sud il vaut mieux le retarder

- la nature du sol

La technique n'est vraiment efficace que si le sol est capable de retenir l'eau. Lorsque les sols sont sableux et (ou) gravillonnaires les possibilités réelles de stockage sont faibles, l'eau percole en profondeur et elle n'est pas utilisée par la plante.

- la position de la culture sur la toposéquence

Le cloisonnement n'a souvent pas d'effet dans les bas fonds où la quantité d'eau est suffisante pour alimenter correctement la culture.

Le billonnage cloisonné apparait dans son ensemble comme une technique d'économie de l'eau très intéressante mais qui doit venir en complément d'autres techniques de préparation du sol si l'on veut lui donner toute son efficacité. Elle peut aussi être combinée au mulch des résidus culturaux.

Cependant le cloisonnement des billons est une opération encore mal mécanisée qui demande un effort particulier de la part du cultivateur. La mise au point d'un apareil adapté est en cours.

Il reste qu'une fois le billonnage cloisonné réalisé, le sarclage mécanique entre les lignes n'est plus possible. C'est une des raisons pour lesquelles il parait préférable de semer à plat après une technique de préparation du sol (labour, travail aux dents) d'effectuer un premier sarclage à 10-15 jours et de réaliser le billonnage cloisonné 3 à 4 semaines après le semis. Dans ces conditions l'herbe est parfaitement maîtrisée.

Le travail du sol dans les sols plus argileux

Les sols dont le taux d'argile des horizons superficiels est superieur à 20% occupent des faibles surfaces en zone semi-aride. Dans les conditions naturelles la structure est bonne et elle peut se régénérer, la tendance à la compaction est plus faible et la porosité permet une croissance racinaire satisfaisante. Dans ces conditions le travail du sol peut ne pas être nécessaire: les techniques de non travail ou de travail minimum peuvent donner de bons résultats.

Pour les *Vertisols* si le profil est homogène et la structure grumeleuse, le travail profond n'est pas nécessaire.

Mais on ne recontre le plus souvent que des *vertisols dégradés*; la texture de surface est sableuse, la structure mauvaise et le profil présente des races de discontinuité. L'infiltration de l'eau est faible ce qui produit engorgement, ruissellement et érosion.

Certains de ces sols (cuvette du lac Tchad) sont utilisés uniquement pendant la saison sèche en raison de leur engorgement. Dans ces conditions le labour avant la plantation a des effets bénéfiques.

Des expérimentations conduites à Hyderabad (Inde) par l'ICRISAT ont montré qu'un aménagement du sol en billons larges de 1,50 m séparés par des sillons qui permettent de drainer l'eau permet l'utilisation de ces sols durant les 2 saisons.

Sur d'autres expérimentations conduites au Burkina Faso sur ces *vertisols dégradés* on a mis en évidence un effet marqué du sous solage qui diminue l'engorgement en brisant la discontinuité.

L'alcalinisation peut aggraver le problème de l'eau dans ces vertisols. C'est le cas des sols Hardés du Nord Cameroun caracterisés par une haute compaction et une très faible dynamique de l'eau. Dans les conditions naturelles ils ne sont pas cultivés.

En construisant de petites digues en courbes de niveau en labourant les champs en fin de saison de pluies on a réussi à cultiver avec succès d'abord du riz puis quelque temps après du coton du sorgho et des fourrages.

Sur les sols hydromorphes temporairement submergés pendant la saison des pluies les effets du travail du sol sont variables. Le labour présente beaucoup d'intérêt pour le contrôle des mauvaises herbes même si les augmentations de rendement ne sont pas très élevées.

Les horizons superficiels des sols ferrugineux tropicaux et ferrallitiques peuvent devenir plus argileux et plus riches en matière organique lorsqu'on va vers les zones humides où la végétation est plus dense. La structure s'améliore, la porosité augmente. Minimum ou No-tillage peuvent alors être appliqués avec plus de succès mais les effets du labour redeviennent rès importants si une sécheresse intervient.

Aménagement du paysage rural

En zone semi-aride les factuers naturels justifient pleinement la mise au point de techniques d'aménagement ayant un double objectif.

- Régulariser l'alimentation hydrique de la plante en éliminant l'excès d'eau et le drainage superficiel
- Protéger le sol contre l'érosion

L'eau est le plus souvent le facteur limitant par défaut, mais peut l'être par excès à certains moments. Le ruissellement peut être important et provoquer des phénomènes d'érosion ou d'engorgement temporaire.

Les techniques d'aménagement du paysage rural les plus utilisées seront rapidement passées en revue.

La culture itinérante

L'alternance de cultures à cycles courts et de longues périodes de repos représentées par une jachère herbacée assurait dans le temps une bonne conservation du sol. En raison de l'augmentation des populations et des superficies cultivées ce système est de moins en moins possible. L'équilibre originel est rompu et la jachère a progressivement disparu dans les régions semi-arides d'Afrique de l'Ouest où dans de nombreux cas ce système est remplacé par la culture continue (pays Mossi, Serère etc). On peut donc dire que la culture itinérante a pratiquement disparu dans les zones semi arides.

La jachère nue cultivée

C'est un système très pratique dans les régions semi-arides tempérées où la capacité de stockage de l'eau dans le sol est supérieure à la pluviométrie annuelle. Pratiquée un an ou plus elle permet de stocker de l'eau et d'obtenir d'intéressantes augmentations de rendement.

En zone semi-aride la forte intensité des pluies excède souvent le taux d'infiltration des sols et la pluviométrie saisonnière totale est souvent plus élevée que la capacité de stockage en eau des sols.

En Afrique de l'Ouest cette pratique est limitée aux sols argileux de la vallée du fleuve Sénégal et dans la periphérie du lac Tchad (vertisols et sols hydromorphes). Pendant la saison des pluies ces sols sont inondés pour la plupart et peu cultivés. On y sème ou repique du sorgho dès que la décrue s'amorce et la croissance s'effctue avec l'humidité résiduelle.

La recherche agronomique a aussi prévu l'utilisation possible de cette jachère nue cultivée dans les régions à faible pluviométrie (inférieure à 400 mm) en ne cultivant qu'une année sur deux de manière à stocker un maximum d'eau dans le sol. Les sols doivent avoir une capacité de stockage suffisante.

Une alternative consiste à cultiver des plantes à court cycle en essayant après la récolte de garder l'eau résiduelle dans le sol en supprimant toute végétation et toute évaporation par exemple par un labour de fin de cycle. L'eau stockée sert ainsi d'assurance contre la sécheresse au début de la saison des pluies suivantes.

Ces méthodes qui revêtent un certain intérêt pour la zone semi-aride ne sont pas généralisables.

Mulch Pailleux

Le mulch pailleux consiste à laisser sur le sol en couverture, tout ou une partie des résidus culturaux. Les objectifs de cette technique sont nombreux.

- Protéger le sol
  - en limitant le ruissellement donc l'érosion
    - en réduisant l'évaporation
    - en régularisant sa température
- Réduire le travail du sol en évitant de remuer les horizons superficiels
- Enrichir le sol en matière organique et accroître l'activité de la mésofaune (vers de terre)

Le mulch pailleux ne diminue le ruissellement et l'érosion que si la quantité de paille présente sur le sol est suffisante. On a montré au Sénégal qu'une récolte de mil de 1500 kg/ha de grain donnant 4 T/ha de paille ne suffit pas à assurer une protection suffisante. Au Burkina Faso l'ICRISAT a montré qu'il fallait au moins 10 T/ha pour avoir un effet réel.

Pour être efficace en terme de conservation de l'humidité et de lutte contre l'évaporation le paillage doit être associé à un désherbage qui ne peut être que chimique et il nécessite donc une certaine technicité.

Durant la culture il assure une certaine efficacité dans la lutte contre l'évaporation tout au moins en début de cycle. Il permet de stocker de l'eau, mais il peut aussi favoriser les percolations dans la mesure où le système racinaire de la plante n'est pas suffisamment développé en profondeur en l'absence de labour.

L'inconvénient du mulch pailleux utilisé seul est justement qu'il ne permet pas de réaliser un travail du sol avec retournement favorable au développement racinaire des cultures.

Le semis mécanique n'est reglé qu'en culture motorisée avec des appareils coûteux. Il n'est donc pas practicable à grande échelle en zone semi-aride.

Enfin il faut que le cultivateur dispose d'une quantité de paille suffisante. Or dans toute la zone Ouest-Africaine semi-aride les pailles sont utilisées comme nourriture du bétail, comme combustible ou comme materiau de construction. C'est donc dans les zones où les problèmes d'alimentation hydrique sont les plus préoccupants que l'on peut le moins mettre en pratique cette technique. Par contre elle garde tout son intérêt dans les zones de défriche récente en milieu tropical humide sur sol à bonne structure.

La culture en bandes

La méthode consiste à cultiver des bandes de 20 à 40 m de largeur épousant les courbes de niveau et à les faire alterner avec des bande étroites (2 à 10 m) de végétation permanente naturelle ou introduite. Cette dernière bien développée ralentit ruissellement et érosion.

Les expérimentations conduites en Côte d'Ivoire et au Niger ont Montré que les bandes enherbées pouvaient réduire les pertes en terre à 1/10 de cel les obtenues sur parcelles témoin.

Pratique et aisée à mettre en oeuvre, la culture en bandes n'immobilise qu'une faible surface du sol (10%). Mais si la pente augmente il faut accroître la largeur des bandes stabilisantes et la proportion de terres non cultivées devient trop importante.

La culture en courbes de niveau

Elle a pour but de diminuer l'érosion du sol, de stopper l'eau par des diguettes et d'accroître aussi son infiltration. Cependant l'érosion superficielle, demeure et une certaine sédimentation peut se produire. Par ailleurs de grandes quantités d'eau peuvent s'accumuler au voisinage des diguettes et l'augmentation de l'infiltration ne finit par concerner qu'une partie du bassin versant. Des problèmes de drainage peuvent se poser en particulier dans les sols lourds.

Des expériences conduites aux Indes montrent que les désavantages associés à la culture en courbes de niveau avec diguette (stagnation de l'eau, absence de drainage, brèches occasionnelles ouvertes dans les diguettes avec pour résultat des chemins d'eau concentrant l'érosion) ont plus de ploids que les avantages venus de l'aspect conservation du sol. Ces conclusions paraissent extrapolables aux zones semi-arides d'Afrique.

Si l'on veut que ce genre d'aménagement réussisse il faut tout d'abord que les cultivateurs se sentent concernés par le dispositif et qu'ils saisissent que les effets à long terme sont importants. Il faut donc réaliser correctement les diguettes en courbe de niveau et les entretenir. Les circonstances sont favorables en raison des conditions de sécheresse qui sévissent dans le Sahel.

Par ailleurs les diguettes en terre sont de plus en plus remplacées par des diguettes en pierres qui limitent le ruissellement et l'érosion en résolvant le problème du drainage. Il n'y a plus d'accumulation d'eau au voisinage des alignements de pierre. Il reste que ce travail qui ne peut être qu'effectué à la main, est long et pénible.

Conclusion

La plupart des techniques de travail du sol et d'économie de l'eau que nous avons examinées sont relativement efficaces quant à la collecte des eaux de pluie (diminution du ruissellement, augmentation de l'infiltration) mais elles n'ont pas toutes les mêmes effets sur l'utilisation par les plantes de cette eau ainsi stockée.

Les différences essentielles, quant à leur efficacité, viennent donc de leur capacité à faciliter le développement du système racinaire des cultures, en particulier en début de cycle, et à permettre la présence en profondeur d'une densité racinaire propre à assurer l'alimentation hydrique de la plante en période sèche.

Cependant aucune technique n'est universelle et chacune doit être adaptée au contexte. L'efficacié de chacune d'elle dépend en effet:

- du sol (texture, structure, profondeur, fertilité)
- du climat (total pluviométrique, répartition)
- de la végétation
- du passé cultural de la parcelle

Enfin le contexte socioéconomique joue un grande rôle dans les possibilités d'application.

Il faut donc faire un choix raisonné en fonction da la situation dans laquelle on se trouve.

Par ailleurs toutes ces techniques doivent être replacées dans le cadre de l'aménagement du paysage rural. Elles doivent venir en complément de la culture en bande, des diguettes en courbes de niveau et autres techniques évoquées précédemment.

Le labour à plat voit son efficacité renforcée s'il est exécuté dans le sens des courbes de niveau entre deux bandes enherbées. Les billons simples donnent de meilleurs résultats s'ils se situent entre deux lignes de diguettes . . . etc.

Si l'on veut arriver à un véritable contrôle du ruissellement et de l'érosion, à une utilisation optimale de l'eau de pluie, il faut intégrer tous les facteurs et combiner entre elles toutes les techniques actuellement disponibles en fonction des moyens dont dispose le cultivateur. Ce dernier doit se sentir concerné par le problème et directement intéressé par les résultats.

PART IV

Farming Systems

RESEARCH AND ANALYSIS OF PRODUCTION SYSTEMS

41 Enhancing the productivity of national agricultural research programmes through farming systems research: the case of the semi-arid areas of sub-Saharan Africa

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Introduction

There are numerous obstacles to improving the crop productivity – and thereby hopefully the welfare – of limited resource farmers in the semi-arid areas of Africa. The problems basically derive from the harshness of the environment for rainfed crops (since irrigation often has limited potential).

In this paper we will discuss some specific research issues that need to be addressed in the semi-arid areas of sub-Saharan Africa. As a backdrop to the discussion we will use a model that describes the potential complexities of different farming systems, and illustrate (as examples) some of the commonalities and differences that exist in farming systems between Botswana and the semi-arid areas of West Africa. This discussion leads to a description of the farming systems approach to research (FSAR), its uses in enhancing the effectiveness of national research efforts, and a discussion of the specific research issues mentioned above.

Defining a Farming System

One possible model of a farming system is presented here to illustrate some of the complexities that a farming system may involve. (Fig. 1).

In developing countries, there is considerable overlap between the unit of production and the unit of consumption. Therefore, the means of livelihood and household are intimately linked and cannot be separated (Figure 1).

A farming system adopted by a given farming household results from its members with their managerial know-how, allocating the three factors of production (land, labour, and capital), to which they have access, to three processes (crops, livestock, and off-farm enterprises) in a manner which, within the knowledge they possess, will maximize the attainment of the goal(s) they are striving for.

The farming system is determined by the environment in which the farming family operates. The "total" environment in which it operates can be divided into the technical (natural) and human elements.

The technical element reflects what the potential farming system can be and, therefore, provides the necessary condition for its presence. The

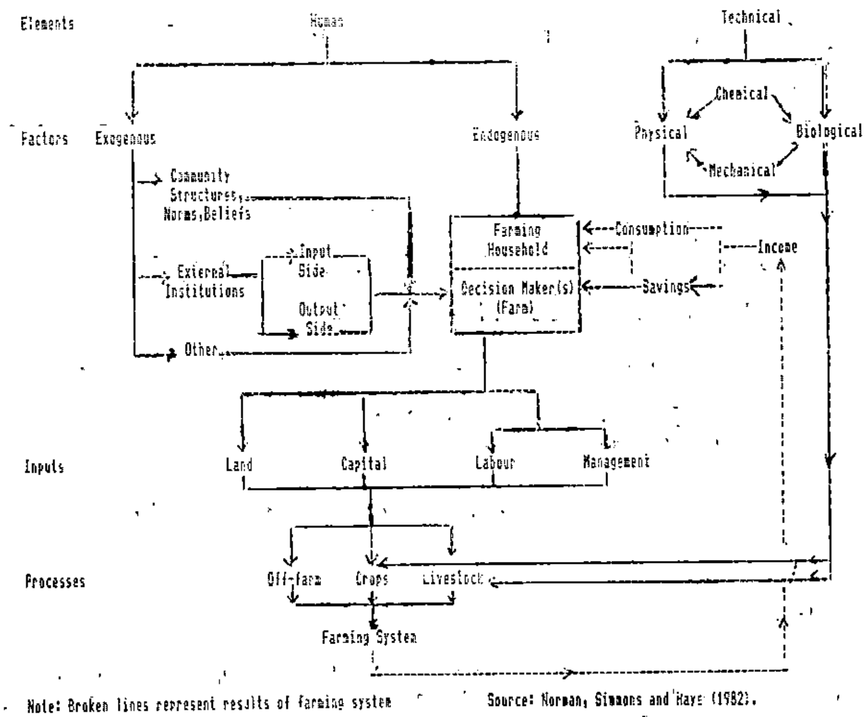

Figure 1 Schematic Representation of Some Farming System Determinants

technical element can be divided into:

a) Physical factors – water, soil, solar radiation, temperatures, etc.
b) Biological factors – crop and animal physiology, disease, insect attack, etc.

Technical scientists have been able to modify the technical element to some extent.

The human element has often been neglected in traditional research approaches to development of improved technologies, which accounts for their often being rejected or, at best, being differentially adopted, thereby resulting in inequitable distribution of benefits. The human element, providing the sufficient condition for the presence of a farming system, determines what the actual farming system will be – ie. a subset of the potential defined by the technical element.

The human element can be divided into two components or groups of factors. The exogenous factors – the social millieu in which the farming household operates – are largely out of the control of the individual farming household, but will influence what its members are able to do. These factors can be divided into three broad groups:

a) Community structures, norms, and beliefs.
b) External institutions or support systems. This is often provided by government, both on the input (extension, input distribution) and product (direct and indirect intervention) sides.
c) Miscellaneous influence – location, population density, etc.

On the other hand, endogenous factors – land, labour, and capital, along with management – which are under the control of the individual farming household, can be used by them to derive a farming system consistent with their goal(s) subject to the boundary conditions laid down by the technical element and exogenous factors. The endogenous factors can under certain circumstances be complimented and supplemented in quantitative and qualitative terms through the influence of exogenous factors – such as capital through a credit programme, management via extension, etc.

Farming Systems in Practice

Examples from West Africa and Botswana illustrate the complexities that can arise in farming systems in practice. These examples also describe some of the similarities and differences that exist between the two areas, and more are presented in table 1.

With specific reference to the technical element:

a) Climate

Unlike temperate areas, where temperatures can be more critical, water is generally recognized as a primary determinant of crop growth in dryland agriculture, both in the West African semi-arid tropics (WASAT) and Botswana. (Matlon 1983, EFSAIP 1985 (summary)). The rainy season coincides with warm summer temperatures in these regions creating a high evaporative demand during the growing season. The months during which rainfall exceeds potential evapotranspiration may be few or none, as is the case in Botswana (Table 1). The erratic nature of the rainfall and the high evaporative demand that exists in intervals between rains can combine to form considerable limitations on crop growth, and cause great difficulty in designing strategies to improve crop productivity for the limited resource farmer.

The semi-arid areas of West Africa are commonly divided into several zones, divided by rainfall isoheights. (Norman *et al.* 1982). The average annual rainfall in Botswana is similar to that of the Southern Sahel zone, but differs in that the same amount falls over a six month period, as opposed to a two to three month period in the Southern Sahel zone. The differences in the amount of precipitation and the length of the rainy season do relate to differences in potential productivity between the different areas, but these differences are more in terms of the severity of the problem, rather than the nature of the problem itself.

b) Soils

The soils of north eastern Botswana are generally low in available phosphorus (Venema 1980). They are also low in organic matter and nitrogen. In the area of the WASAT, on-station experiments have shown good response to NPK fertilisers in a number of crops, including maize and sorghum and a smaller response in millet (Matlon 1983). While soil fertility and plant nutrition are undoubtedly a problem in both areas, the use of commercial fertilisers among farmers remains very low (with the exception of use on some cash crops in the WASAT) (Matlon 1983, ATIP 1984). In light of some on-farm research findings this is not surprising. Responses of cereal crops to fertiliser use under farmer managed conditions are often highly variable, even in years of reasonable rainfall, and may not be economic at all in areas where rainfall is less than 700 mm. (Matlon 1983, ATIP 1985).

Table 1 Contrasts of Selected Aspects of Agricultural Systems Between Tutume District, Botswana and Zaria, Nigeria.

Location:	Tutume District, *Botswana*	Zaria *Nigeria*
Climate:		
Rainfall (mm/yr)	470	1100
Rainfall > PET (months)	0	4
Length of growing season (months)	6-7	5-6
Soils:	P-deficient	P-deficient
Farm Size:		
Cultivated land (ha)	5.1	3.2
Fallow land (ha)	11.5	0.7
Total (ha)	16.6	3.9
Any irrigation?	No	Yes
Field Fragmentation	No	Yes
People		
Religion	Christian	Moslem
Residences	Village, lands, cattlepost	One
Family size	7.7	
Major "income" sources	Crops, livestock, off-farm, remittances	Crops, smallstock off-farm
Cropping:		
Major Crops	Millet Sorghum Cowpeas Watermelons	Millet Sorghum Cowpeas Groundnuts
Mean Sorghum Yield: (kg/ha) (on-farm)	300	800
System:		
Power source	Animal	Hand
Land prep.	Flat	Ridge
Planting system	Broadcast	Row
Sole/mixed crop	Mixed	Mixed
Weeding	1	2-3
Fertilizer	Little	Manure & inorganic
Livestock uses	Draught	Manure, transport
Percent breakdown of cropping labour:		
Family: Adult males	14	72
Adult females	39	1
Children	14	9
Hired	33	18
Peak labour demand *Period for crops:*	Most: plough/plant Less weed/harvest	Weeding Harvesting

c) Crops

There is more emphasis on cash crops in West African farming systems than there is in Botswana. However, in terms of food crops there is more commonality, with sorghum, millet and cowpeas being important staples in both areas.

Thus with low and variable rainfall and soils of moderate to low nutritional quality, farmers face a somewhat comparable crop production environment. With severe limitations in the technical environment farmers pursue a number of different strategies to try and increase their income security. These strategies represent part of the human element in developing a farming system. Some examples, together with their implications are as follows:

a) Planting Crops in mixtures

In Tutume District, Botswana, essentially all limited-resource farmers plant the majority of their field area to mixtures of crop species. This practice is also common among limited resource farmers in the WASAT and in many other areas of Africa. Planting crops in mixtures often enhances the stability of income from crop production activities for a number of reasons including: 1) The different crops progress through their growth cycles at different rates and are sensitive to environmental stress at different times. Stress at any particular time may have serious effects on one crop, while another crop may be less susceptible at that time. 2) The crops may differ in susceptibility to different types of pests or environmental stress (eg. Sorghum grain is very susceptible to bird damage as it matures, whereas, in Botswana, maize and watermelons may not be). 3) Partial failure in one crop may be partially off set by compensatory growth in another. Further, it has been shown that, in the area around Zaria, planting crops in mixtures helped to alleviate the labour bottleneck in terms of physical work and increased the returns to labour during the bottleneck period. (Norman, 1981).

Thus, planting crops in mixtures may be a useful strategy to address a number of problems including the variations inherent in a harsh environment and some endogenous constraints like limited family labour.

It should be noted, however, that major differences do exist in the cropping patterns between Botswana and the WASAT. Though planting of crops in mixtures may be done for some of the same reasons, the way in which crops are chosen and arranged may be quite different. For example, in the area around Zaria, Nigeria, the planting of food crops is usually done by hand, on ridges. Specific crop species may be chosen for a field, depending on distance from the dwelling, and within a field crops are commonly arranged in a very specific and regular pattern which allows for the differing growth habits of different crop species. (Norman *et al.* 1982). This is not at all the case in Botswana, where fields are not fragmented and most food crops are simply broadcast over the field in a mixture and then ploughed under. Thus spatial arrangements of crop species are largely due to chance, and much more difficult to work with from a scientific point of view.

b) Intensification of Production

Where land is not limiting, crop production systems tend to be extensive, with few activities or inputs aimed at maximizing yield per unit area. For example, in Botswana, planting is done by broadcasting seed and ploughing it under with an animal drawn mouldboard plough. The usual strategy is to plant as large an area as possible on each planting rain. Traditionally there is very little use of manures or organic residues for improving productivity, and the only operations between planting and harvest are a single weeding, and bird scaring when necessary. However where land is used more intensively – due to increasing population pressure or proximity to dwelling areas – soil fertility may degrade rapidly. Under such conditions, relationships between crops and livestock change and the use of manure as fertiliser becomes more important. In the ring system of cultivation in Nigeria, land under permanent cultivation near the compound may receive regular incorporation of organic residues. (Norman *et al.* 1982).

Diversification

Crop production in semi arid areas is seasonal and often unreliable. Also, farmers often have a number of objectives beyond production of food for subsistence requirements. (eg. some cash income may be desired.) So farmers meet their differing objectives and cushion themselves against extreme income fluctuation by spreading their resources among different enterprises. In less extreme environments of the WASAT, where technology packages are available and the environments permit, farmers may seek diversity in different cropping enterprises. For example, cereal grains and legumes are grown for home consumption, while cash crops such as cotton and/or groundnuts are grown to meet income requirements. In more extreme areas like Botswana, where crop production is a high risk proposition, diversification tends to be in the direction of non-cropping options to a greater extent (eg. livestock enterprises and off-farm employment).

Each different enterprise requires the investment of limited family resources. Greater investment in one particular activity will require that less be invested in another enterprise. Because of this, farmers attempting to balance their resources to meet various objectives will, in their "decision equation" take into account the potential level of return and the potential dependability of that return from their different investment opportunities. In more marginal environments (such as Tutume District, Botswana) returns to investments in rainfed crop production are traditionally low, and not dependable. Hence a farmer's decision on whether to invest available resources in rainfed crop production is not likely to be favourable beyond a certain minimum. Where that is the case, it makes the task of improving crop production particularly difficult since it implies that there can be little increased reliance on purchased inputs such as fertilizers or spraying equipment. (And, among agronomists, increased reliance on purchased inputs is a common approach to increasing crop productivity). A further implication is that increases in reliability of production are likely to be as interesting to farmers as increases in actual amounts.

d) Short Term Versus Long Term Investment

In these uncertain production environments, the closer a farming family is to the subsistence level, the more likely they are to pursue short run survival goals at the expense of long run issues – such as maintenance of ecological stability. For example, a family close to the subsistence level may not be able to afford the labour to repair erosion gullies on their own land if the same labour can be employed for needed cash elsewhere. Similarly, within a cropping season, such a family may prefer to weed someone else's field for a guaranteed cash return, rather than weed their own field in a timely manner, since the returns from weeding their own field are both in the future and not guaranteed. Increasing crop productivity and generating concern for ecological stability within such a group may be extremely difficult, because such a large percentage of their available resources are required to meet immediate needs.

The Farming Systems Approach to Research (FSAR)

The above discussion implicitly illustrates the potential problems that can arise from a lack of contact between the developers of improved technology (the national researchers) and the customers of those technologies (the farmers). Africa is littered with examples of so-called relevant technologies that have not been adopted by farmers. The reason why this has occurred may be simple, but the resolution of the problem is more complex. In commerce the critical nature of the link between the "technology developer" and the "customer" has long been recognized, but this lesson, until recently, has not been absorbed in Agriculture. The FSAR, which in Africa has become popular in the last decade or so, is designed to forge such linkages.

It is not within the scope of this paper to discuss in detail the farming systems approach to research. However, a brief overview is presented here as a point of reference and a schematic diagram is presented in Figure 2. The four stages of research can be delineated as follows:

1) The *Descriptive or Diagnostic Stage* in which the actual farming system is examined in the context of the "total" environment – to identify constraints farmers face and to ascertain the potential flexibility in the farming system in terms of timing, slack resources, etc. An effort is also made to understand goals and motivation of farmers that may affect their decision to participate in efforts to improve the farming system.

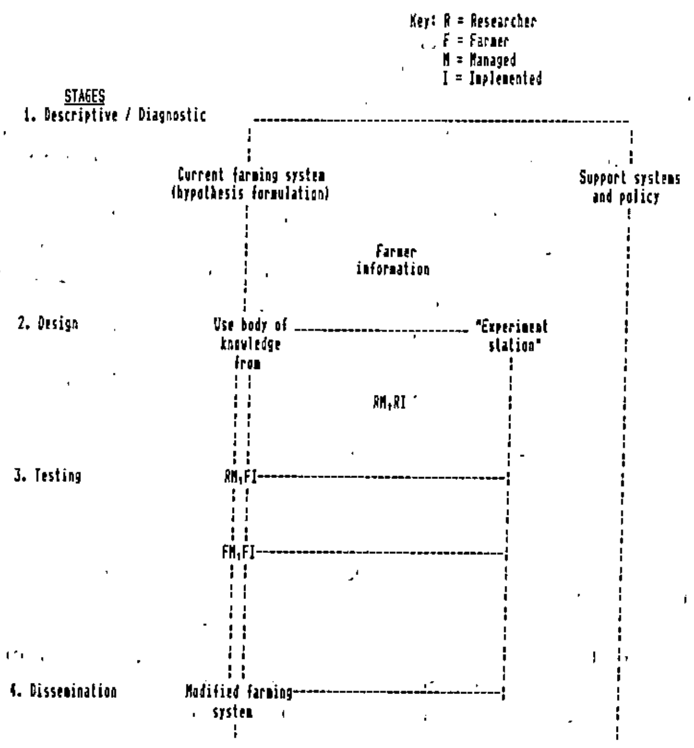

Figure 2 Farming Systems Research

2) The *Design Stage* in which a range of strategies are identified that are thought to be relevant in dealing with the constraints delineated in the descriptive or diagnostic stage. Information for designing such strategies comes from experiment station work, researcher managed and researcher implemented (RM,RI) work on farmers' fields, and from other farmers.

3) The *Testing Stage* in which a few promising strategies arising from the design stage are examined and evaluated under farm conditions to ascertain the suitability for producing desirable and acceptable changes in the existing farming system. This stage consists of two parts; researcher managed and farmer implemented (RM,FI) trials and finally farmer managed and farmer implemented (FM,FI) testing, which is the final level of testing of a proposed improved strategy.

4) The *Dissemination Stage* in which the strategies that were identified and screened during the design and testing stages are implemented.

In fact there are no clear boundaries between the various stages. Design activity, for example, may begin before the descriptive and diagnostic stages and may continue into the testing stage as promising alternatives emerge from researcher managed and farmer implemented trials – where farmers and researchers interact directly. Similarly testing by farmers may mark the beginning of dissemination activities.

In essence the approach involves putting the farmer, as the consumer of the improved technologies, in the centre of the stage. In addition the approach involves tapping the body of knowledge possessed by farmers, requires the use of an interdisciplinary approach, increases the emphasis on exploiting complementary and supplementary relationships in the farming system, involves the dynamic and interactive approach and is complementary with the experiment station based agricultural research. With reference to the last attribute the farming systems approach contributes in two ways:

a) By fine tuning, through adaptive testing at the farm level, technologies developed on experiment stations. Successful testing gives rise to successful dissemination (all other things being equal) resulting in the improvement of farming families welfare.
b) By responding to failure under adaptive testing at the farm level. This results in closer specification of requirements for improved technology development that can be fed back to experiment station based research programmes. Hopefully, this will contribute to the cost efficient development of improved technologies that will improve the welfare of farming families in the future.

Analogous linkages, although rarely done to date, could be established with planning and development agencies with reference to proposed policy/support programme changes.

The involvement of farmers in FSAR gives them a voice in the research process and ensures the use of evaluation criteria relevant to them. For the farming family, evaluation criteria for the adoption of the improved technologies can be divided into the following groups, although it should be emphasised they are not necessarily mutually exclusive:

a) Necessary conditions determine whether the farming family *would be able* to adopt the improved practices. Such conditions include technical feasibility, social acceptability, and compatibility with external institutions – that is support systems.

b) Sufficient conditions determine whether the farmer *would be willing* to adopt the improved practices. Obviously the necessary conditions will be influential in determining this willingness. Sufficient conditions include the compatibility of the improved practices with the goal(s) (self sufficiency, profit maximization, etc) of the farming family, the resources they have access to, and the farming system they currently practice.

Two items critical to increasing crop productivity in the semi-arid areas of sub-Saharan Africa today are: 1) Generating truly appropriate and practical technological innovations and; 2) Developing appropriate policy support systems. The FSAR is an important tool for rational development of these objectives.

Strategies for Improving Crop Productivity in Semi-Arid Areas of Sub-Saharan Africa

It is apparent from the earlier discussion that without close contact between researchers and farmers, technologies may be developed which address the needs of the technical element, but not that of the human element. Without the use of FSAR, such technology may be neither relevant nor appropriate for the limited resource farmer. Efforts to improve the productivity of cropping systems will require dealing with several interrelated problems. Some of the major ones include: rainfall conservation and efficient use of water available for plant growth; timeliness of operations particularly planting and weeding; a loss of potential for regenerating soil fertility due to replacement of shifting cultivation by continuous cropping; sometimes inadequate and uncertain supplies of high quality seeds and other potentially useful inputs; weeds; and, in some areas, bird damage. Another major problem that perhaps should be emphasized is the heterogeneity of the farming populations for which technology and policy support are to be developed.

Because of the range of issues and the complexity of farming systems, it is important to have clear, effective strategies for implementing FSAR to improve cropping productivity. We suggest that the following issues need to be addressed in the development of appropriate research strategies. The first three deal with subject matter priorities, and the remaining six refer to methodological issues:

Subject Matter Issues

a) Water:

Within the semi-arid areas of sub-Saharan Africa, water is a major limiting factor (if not *the* major limiting factor) for crop production under rainfed conditions. Obviously then, water management is a critical issue (together with run-off and erosion control).

Within this issue there are two basic levels of technology. The first level involves "macro" technologies that would probably require strong policy support from governments. Examples include watershed management projects, terracing projects, laying out contours, etc. Research projects on technology at this level would probably be long term in nature (especially regarding pay-offs) and require government backing from the outset. In terms of preservation of natural resources they are critical.

At the second level are "micro" technologies that farmers may be able to implement themselves, such as deep ploughing (>220 cm), ridging, tied ridging, mulching etc. Considerable research has been done on some of these options in the last decade, both in Botswana and the WASAT. Results from both areas are often strikingly similar, suggesting that a greater exchange of information on results and ideas could be beneficial. A primary conclusion in both areas has been that to give the greatest increases in yield, tillage systems must seek to maximize soil porosity (Nicou and Charreau 1985, DLFRS 1985).

The importance of soil physical properties in water infiltration and availability for plant growth, and the different response of soil types to specific tillage practices, point to the need for the involvement of soil scientists in this type of work. Understanding how and why certain land preparation practices work is necessary to determine where and when specific practices should be used. This information is vital for extension recommendations. Understanding the long term effects of different tillage practices may also be important. The role of soil science in this type of research needs to be emphasized.

Regarding the development and implementation of different tillage/planting strategies, timing is often important for maximizing water infiltration and availability for germination and plant growth, particularly in semi-arid areas, because of the low level and high variability of rainfall. However, the ability to pursue "timeliness" is not a function of management alone. It also depends on the farmers' resources. For example, in Bostwana, farmers may own, borrow or hire draught power for ploughing. The type of draught power may be donkeys, oxen or tractors, all of which have differing rates of operation and depths at which they can work. Obviously, it is much easier for a farmer who owns a tractor to perform timely operations than it is for a farmer who has to hire donkeys. The challenge is to develop relevant technologies for farmers with different levels of resources. In the case of timely ploughing, this will probably involve different types of equipment and possibly different planting options.

b) Crop-Livestock Interface:

Most people involved in agricultural research in the semi-arid areas of sub-Saharan Africa would probably agree that there is a potentially very important linkage between crop and livestock enterprises. Animal manure could be useful for maintaining and improving soil fertility and structure; cattle and donkeys can provide draught power for tillage work and transport of farm produce; and crop residues and fodders could provide an important source of animal feed. However, in many places these potential linkages are apparently underutilized. For example, in Tutume District, less than 10% of the population apply manure to their fields, and the majority of farmers do not possess ox-carts, though 70% of farm families own cattle. (ATIP 1985) Underutilization of these potential links may exist for a number of complex reasons imposed by cultural, environmental and labour constraints. Improving the linkages may also be difficult from a research point of view because of the number of disciplinary areas involved, which include animal husbandry and nutrition, agricultural engineering, economics, sociology and agronomy. None the less it is a potentially very useful area for technology development and should not be overlooked.

c) Environmental Degradation:
The recent drought that covered large areas of Africa focused much attention not only on the short run needs of people in the drought stricken areas, but also on the root causes that exacerbate the negative effects of less-than-normal rainfall. Much of the problem lies with large scale environmental degradation – the effects of deforestation in densely populated areas, over grazing which destroyed the soil cover and increases erosion and water loss, and degradation of soil quality through intensified use without intensified soil maintenance measures.

Reversing this trend is necessary, but there are no quick-fixes. It will require a long term sustained effort on the part of governments, and probably will be dependent upon government policies for implementation.

The FSAR may not be well adapted to addressing the long term needs of society. As a tool, the FSAR is probably best suited to developing strategies to address the shorter-run felt needs of farm families. The FSAR may assist in the development of technological solutions to long term societal problems through providing descriptions of the social and environmental matrix into which the technologies must fit, and perhaps assisting with assessing the problem and testing parts of the technology in the field. Scientists involved in the FSAR could also contribute by working to develop systems alternatives that are self sustaining in the long run. But in the end, this type of work will probably depend on government policy support, and large scale projects that may be largely outside the realm of the FSAR.

Methodological Constraints

a) Breaking Constraints Versus Exploiting Flexibility:
Constraints to crop production can be addressed in two ways. The constraint can either be avoided, by exploiting flexibility in the ssytem, or it can be broken directly. A technical example could be a sorghum disease which could either be avoided by planting the crop at a sub-optimal time (exploiting flexibility in the sytem) or overcome by the use of a seed dressing or resistant genotypes (breaking the constraint).

In areas like Tutume District, the very low level and highly variable nature of the rainfall makes the timeliness of operations critical and ties agricultural activity tightly to rainfall occurrences. In such environments there is little flexibility in the system, and it becomes necessary to break constrains in order to improve crop productivity. This is usually more difficult than exploiting flexibility, both for researchers and for farmers. Evolving solutions will likely be a longer process, and the technical solution may be complex or expensive. It is necessary for technology designers to remember also that in such high risk envrionments farmers may not be interested in large investments in crop production and may not be concerned with producing more than their subsistence needs. This places greater limits on the types of technological solutions that can be used to break production constraints.

One of the implications for research in environments with relatively little flexibility, is that it may be necessary to devote more of the total research budget to long term, on-station research, as opposed to on-farm adaptive research. For example, in an environment with limited flexibility such as Tutume District, examining different possible crop mixtures on farmers' fields may result in only marginal gains because the potential of *any* mixture will still be severely limited by the water constraint and stand establishment problems. It might be more useful in the long run to invest relatively more in on-station research, developing locally adapted, drought resistant crop genotypes, in finding improved water management factors that would in effect modify the cropping environment, or in examining the potential payback to the nation from large scale soil and water conservation operations like terracing, contour bounding, or agro-forestry.

This does not mean that on-farm research would not be necessary. On-farm research would still play an important role in identifying farmer constraints and in testing and adaptation of any potentially useful technology options. But the role of on-farm research might well be less than in areas of higher rainfall where there is more flexibility in the system and therefore more potentially useful technology options immediately available to test and adapt.

It might be useful for research planners to consider the severity of environmental constraints and the number of potentially useful "on-shelf" technology options available when deciding how to allocate resources between on-station and on-farm research

b) Recommended Practices Versus Decision Trees:

It is common practice for research organizations to recommend certain standard practices or packages of practices. For example, in Bostwana it is recommended that farmers plough their fields after harvest and again at planting time. And it is recommended that farmers apply a minimum of 20 kg/ha of phosphate on cereal grain plots. Recommendations such as these are generally beneficial when they are followed.

However, the semi-arid areas of sub-Saharan Africa are characterized by much within and between season climatic variation. And farmers themselves often have variable access to different resources. (eg. Draught animals may get sick, or get lost at inopportune times, labour may be more available when children are free during school holidays, etc). Thus, most often, a farmers' "system" in a given year develops as the season progresses, in response to what is happening in their fields, and based on their changing pool of resources and perceived family priorities among their various household enterprises. A common example from Botswana would be the case where emergence on a recently planted lot was extremely poor. The farmer must then decide whether to broadcast seed and replough the plot on the next rain, – this would constitute double ploughing of the plot which often has beneficial effects on yield in Bostwana – Whether to replant portions of the plot by hand, or whether to simply plant another plot on the next rain and hope that more seedlings will emerge on their own in the first plot. Research could help distinguish the relative merits of replanting versus gap filling. Suppose the farmer replants and establishes an excellent stand. This is followed three weeks later by another good rain, should the farmer plant again, or concentrate on weeding the first crop. Thus the farmer makes serial decisions that perhaps research could assist with.

While an optimum package of recommendations may be desirable and useful, research that addresses farmers' contingency options – or recommendations developed for a decision tree type approach – may have relevance to a wider range of farmers, and may be more easily adopted.

c) Heterogeneity of Farming Populations:

This is an important but complex subject which we touch on only briefly here.

Within a farming community, farming units have different levels of resources available for crop production. In Botswana, for example a common division among farmers (employed by researchers) is in terms of access to draught power. Some farmers own tractors, others cattle and/or donkeys. Many farmers do not own any draught power and rely on borrowing or hiring tractors, cattle or donkeys to plant their fields. Clearly, technology that depends on access to certain draught resources will be appropriate to some members of the community, but not to others. For a farming community then, there is a need to develop different technology options for farmers with access to different resources.

This situation is made more complicated by complex inter- and intra-household relationships in terms of control over the factors of production (Norman *et al.* 1982, Behnke and Kerven, 1986). Thus it may be difficult for research scientists even to define a specific farming unit, and the total resources available for use by that unit. This in turn may retard the development of "appropriate" technologies. Further, without a broad understanding of inter- and intra-household relationships, technologies developed may have a beneficial effect for some households, and a negative effect on others. (eg. If a system of poughing twice instead of once – for better rainfall conservation – became popular in Tutume District, it might increase the productivity of draught power owners, but make draught power less available to the 30% of the population that relies on borrowed or hired draught power). Thus a greater understanding of inter- and intra-household dynamics might aid researchers in developing truly appropriate technology, and help them to find ways to improve the productivity of whole communities, rather than individual families.

d) Evaluation Criteria

The criteria that farmers use to evaluate technologies may be quite complex. For example many farmers in Tutume District typically plant small plots of mixed crops whenever a good rainfall occurs, across several months. This may be necessary because animal draught power is not fast enough to plant large hectarages in the brief planting periods that follow small showers. But it may also be desirable because it spreads the risk of crop failure and spaces the labour requirements over a wide period. Planting a large area under optimal environmental conditions with a tractor might improve biological yield potential, but leave the farmer with the impossible task of hand weeding the whole area in a short period, and simultaneously increase the farmers' risk.

Assessing a technology on the basis of yield per unit land area, while disregarding its wider effects on a farmers' system – such as increased labour requirements and risk – may result in the extension of inappropriate technologies which subsequently may not be adopted.

Complicated evaluation criteria are often difficult to discern, let alone apply to small plots on a research station. At present, the best and perhaps only – way to properly evaluate a technology option is through testing the technology with farmers, and obtaining their assessment before the technology goes to the dissemination stage. (This is one of the major contributions of an FSAR). However, even obtaining an unbiased assessment from farmers may be difficult. The question of how to properly evaluate new technology options is challenging, and would be a very useful area for input from anthropologists and rural sociologists.

e) Linkages Between On-farm and On-station Research in FSAR:

The FSAR is not simply on-farm research. Rather it is an approach that seeks to link different groups (Researchers, extension personnel and sometimes policy makers) and assist them to focus jointly on problems relevant to farmers. As such, the link between on-farm research and on-station commodity research groups is essential.

The role of on-farm research is to:

1) Test and adapt technology options to farmer conditions; and
2) More closely specify the requirements for improved technologies in the field, and describe the limitations into which technology must fit.

The latter is often primarily to assist station based research. On-station research is necessary for a number of reasons including basic research on and development of new ways to break constraints and in helping to solve other technical problems in the field, especially where well controlled conditions are necessary for specific types of experiments and procedures. Thus the two groups are necessary to support each other.

However – despite the commonalities – good links between the two groups are often difficult to establish. This happens for numerous reasons. Some of the major reasons include geographic separation; mutual disrespect (on-farm workers think station based researchers are not operating in the "real world" whereas station based researchers view on-farm experimentation as non-rigorous and of questionable significance); there may be competition for scarce resources; the roles of the two groups may be undefined and channels of communication unspecified, leaving the two groups unsure as to how they are supposed to interact; and sometimes interaction with on-farm research is not within the mandate of station-based research groups. The latter two problems are particularly likely to occur when "on-farm" or farming systems projects are superimposed on an already existing research structure.

There are numerous ways to promote interaction between on- and off-station research, the best of which is probably to have researchers collaborating on experimental work in both arenas. The way the interaction is developed will depend on the goals of the research administration and the geographic arrangement of the research system. However, three important criteria will help promote the interaction; 1) research staff must have collaboration within their research mandate, so that they can allocate the time; 2) funding must be available to allow the necessary travel; and 3) there must be active encouragement for interaction from leaders of the research system. Meeting these three criteria will help ensure that the full potential of the FSAR for technology development is realized.

f) Links With Development Activities:

This topic is not discussed in detail here, as it is only indirectly related to the subject of the paper. However, it needs to be pointed out that linkages between farming systems research and development agencies are necessary if research findings are to have a wide reaching impact. Few effective formal linkage systems have evolved. In practice, the most common and effective linkages have been the informal linkages developed by field workers at the local level. This is an area that still presents difficulty in the process of formalizing an FSAR.

Conclusion

Two major problems that inhibit the development and dissemination of relevant improved technology in the semi-arid areas of West Africa and Botswana are: 1) The low level and erratic inter- and intra-year distribution of rainfall, on which most crop production depends; and 2) the heterogeneity of the farming population (in terms of both personal objectives and access to resources for which technology and policy support systems are to be developed.

The FSAR is a practical tool for ensuring the relevance of research to felt needs of the limited-resource farmer, and is being put into practice in many countries in Africa. However, where on-going research systems are already in place, building a niche for the FSAR may be somewhat complicated (especially in regards to the allocation of staff and the roles of various staff members).

There are many methodological and implementation issues still to solve in the FSAR, which is not surprising perhaps, since the actual use of the FSAR is still relatively new in many countries of sub-Saharan Africa. But the consensus seems to be emerging that the FSAR, together with the establishment of good links between on-farm research and on-station component research groups, can help in improving the research product – and thus, hopefully, the welfare of limited resource farmers in the semi-arid areas of sub-Saharan Africa.

Hopefully this paper has highlighted several points that need to be emphasized in order to realize the practical benefits of the FSAR.

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42 Factors Affecting Smallholder Grain Production in the Ethiopia Highlands

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Abstract Livestock play critical production roles in the majority of smallholder farming systems in sub-Saharan Africa. Oxen are widely used in the continent as draught animals and are especially important in Ethiopia where some 7m oxen are routinely harnessed for work. These oxen are used both in low risk and high risk farming systems. This paper documents the factors which influence grain production in a representative and risky farming system in Ethiopian highlands. The analysis gives quantitative evidence of the critical contribution of draught oxen to farm grain production. Farmers without oxen are shown to produce significantly less grain than farmers owning either one ox or two oxen. These production differences arise due to a combination of positive effects of oxen ownership on both area cultivated and yield per unit area. Policy implications of the analysis are drawn in relation to development schemes to increase supplies of oxen to individual farmers owning less than the traditional pair of oxen.

Introduction

Over 80% of Ethiopia's human population of 42 million live in rural areas of the highlands and are dependent upon smallholder agriculture for their livelihood. Agricultural productivity is stagnant, the consequences of which are most acute in the higher and cooler agricultural areas where environmental factors severely limit the impact of modern crop technologies. The devastation wrought by the recent drought in Ethiopia bears witness to the need for more productive agriculture.

The Baso and Worena Wereda in Tegulet and Bulga Awraja of Shoa Province is representative of the cooler temperate agricultural systems in the Ethiopian highlands.[3] It is principally a plateau area at around 2800m a.s.l. Farmers there cultivate cereals (wheat, barley and oats) and pulses (horse beans – *Vicia faba*, field peas – *Pisum sativum* and lentils – *Lens esculenta*). Small areas of speciality crops such as linseed are also sown. A general description of this system is given in Gryseels and Anderson (1983).

Livestock, almost exclusively of local breeds, are an integral part of the farming system, with their most important contribution being the draught power produced by oxen used for cultivation. Livestock, and especially sheep, account for a major part of farmers' cash incomes. Manure is the dominant household fuel. Hides, skins and milk are also important products.

Table 1 presents a summary of the rainfall data and estimated lengths of crop growing period (LGPs) for 1978-1984 based upon data collected at the ILCA Debre Berhan research station located in Baso and Werena Wereda.

[3] Awrajas are administrative units comprising several Weredas. Provinces are composed of several Awrajas. Addis Ababa is in Shoa Province.

Table 1 Annual precipitation and estimated lengths of short and main growing periods at Debre Berhan, 1978-1984.

Year period[b]	Total precipitation[a] (mm)	Length of short growing period[b] (days)	Length of main growing (days)
1978	681	0	132
1979	961	51	168
1980	1068	15	150
1981	978	66	129
1982	1009	48	135
1983	897	93	114
1984	869	0	168
Average	923	39	142

[a] Data for 1978 are from National Meteorological Service Agency records; 1979-1984 data are from ILCA, Debre Berhan.
[b] Estimated by assuming 50mm of water storage in the topsoil.

The LGPs in that table were derived from the application of a water balance model which assumed maximum water storage of 50mm in the topsoil. The model is described in Henricksen and Durkin (1985). The analysis suggests the area experiences a mean growing period each year in the main cropping season in excess of 140 days. In practice the growing season is truncated by frosts early in October resulting in a crop growth period which can be as short as 90 days. Hail causes considerable crop losses each year during the early part of the growing season. Crop production is problematical although the area receives a relatively high average annual rainfall.

Most of the land sown to crops in the main season is on the higher slopes away from the more frost-prone valley bottoms, requiring farmers to use shallow, erodible and relatively infertile soils for their crops. Crop yields are low as a consequence of these and other factors and the annual harvests are becoming less able to support the progressively increasing human population. Farmers now produce only about 10% more grain than they require for home consumption.

As elsewhere throughout Ethiopia, all farmers in Baso and Worena Wereda are members of a peasants association (PA), with each PA having considerable autonomy over the use and allocation of land within its boundary. A nominal 800 ha is assigned to each PA and will support some 150-250 farm families. The formation of PAs was a central element of the national land reform enacted in 1975. Individual farmers within a PA have user's rights over the land they till, with the area allocated to each farmer being based on need as reflected by family size, the availability of crops and pasture land per family within the PA boundary, the individual's ability to use the land allocated to him, and local custom.

A study by Giglietti and Stevan (1986) has highlighted the differences in land resource endowments between PAs, even adjacent ones. This diversity is a feature of agricultural production in much of the Ethiopian highlands. Farms are fragmented with strong differences in soil types and qualities within a PA. Fallow periods of up to 15 years have been reported. Farmers usually plant at most two cereal crops and one pulse crop before returning the land to fallow.

This paper reports an analysis of some factors affecting farm cereal and pulse production on smallholder farms in the Debre Berhan area. This area is representative of large parts of Ethiopia where production gains must be made at the smallholder level in order to provide food security for the resident population in the coming years. The critical contribution of draught oxen to grain production is highlighted.

Materials and Methods

From 1979 to 1984 ILCA conducted intensive production surveys of traditional farms in Baso and Worena Wereda to provide data on the system. These surveys were part of a larger research programme focussing on ways of increasing farm production by improving the livestock component of farming systems in the area. ILCA established a research station near Debre Berhan in 1979. The research has been undertaken with a farming systems perspective where the problems and circumstances of farm production are used to guide the selection and conduct of station-based research. Testing of positive results from station research is done on farms by farmers before they are disseminated widely through the national development and extension agencies. The data collected in the surveys with traditional farmers provide information to guide technology design and a baseline against which the impact of changes following from the introduction of new technologies can be measured. Farmers who test new technologies are not included in the baseline surveys of traditional farms.

Data were collected over the six-year survey period for a total of 237 farmer-years from farmers who were members of four PAs proximate to the ILCA research station. The original sample was drawn at random from the lists of members held at each PA office. This data set includes only those farmers who were in the sample for a minimum of three years. The four PAs were Faji/Bokafia, Karafino, Kormargefia and Melki. Each year about 20% of the farmers whose data were collected in that year did not participate in the following year and were replaced by farmers randomly selected from the other farmers in the PAs. Farmers did not continue with the survey for various reasons including moving out of the locality, retiring from farming, joining with other farmers in cooperative farming, and 'survey fatigue'. The total survey included approximately 40 farmers each year, about 20 from each PA, which was approximately a 5% sample.

Farm data were collected through direct measurement, observation and formal interviews which at critical times of the year were made at most two times a week. The analysis presented here uses only the data collected on cereal and pulse production. Field measurements of cropped areas, seeding rates and gross yields were taken for all plots sown to cereals and pulses. Data from all plots of the different cereals and pulses were consolidated into separate data sets on a whole-farm basis by year for each farmer. A total of 226 farmer-years of data were available for pulses after eliminating from the analysis those farmer-years when a farmer did not grow pulses in a particular year. Data on pulse and cereal production were analysed separately because they have different labour requirements and profitabilities. Additionally, cereals and pulses do not have equivalent feeding values as regards energy and protein concentrations. Cereal straws account for an important fraction of ruminant feed supply, while pulse stover is not fed to livestock.

The data were analysed by least squares procedures (Harvey, 1977). Combined analyses were made with the following parameters as dependent variables: total cereal area; total cereal seed use; gross and net cereal production; cereal seed use per ha; gross and net cereal yield per ha; pulse area; total pulse seed use; gross and net pulse production; pulse seed use per ha; and gross and net pulse yield per ha.

The model included the random effect of farmer within PA and the fixed effects of peasant association, year of planting, number of oxen owned at time of planting, fertilizer used (yes or no) for cereals only, and interaction terms for year by oxen ownership and PA by year of planting effects.

Household size (a proxy for labour supply) and total livestock holding excluding oxen were used as covariates. Household size was calculated using weights of unity for adults, 0.5 for each child between the ages of 10 and 15 years, and 0.25 for each child aged six to nine years. Mid-year household composition was used for these calculations. Livestock holding excluding oxen is expressed in Tropical Livestock Units with one TLU being equivalent to 250 kg liveweight. Inventories at mid-year, just prior to the main crop season, were used to calculate this index.

Results

Overview of survey data

Table 2 summarizes the survey data reported upon in later sections. It gives the means, standard errors and coefficients of variation for all parameters. The coefficients of variation of the observed parameters were large.

Table 2 Survey data means, standard errors and coefficients of variation for farm cereal (n=237), and pulse (n=226) production in Debre Berhan, 1979-1984.

Parameter	Mean	Standard error	Coefficient of variation (%)
Cereal area (ha)	1.803	0.052	44.2
Total cereal production (t)	1.259	0.052	63.0
Cereal seed (t)	0.264	0.010	57.2
Net farm cereal production (t)	0.995	0.046	71.0
Cereal yield (t/ha)	0.693	0.021	46.4
Cereal seed (t/ha)	0.143	0.003	34.4
Net cereal yield (t/ha)	0.545	0.020	57.1
Pulse area (ha)	0.617	0.029	70.9
Total pulse production (t)	0.415	0.025	92.2
Pulse seed (t)	0.102	0.005	75.2
Net farm pulse production (t)	0.313	0.022	90.6
Pulse yield (t/ha)	0.682	0.032	70.2
Pulse seed (t/ha)	0.177	0.007	61.6
Net pulse yield (t/ha)	0.501	0.030	105.6

Table 3 Mean square (x 100) for farm cereal production parameters for Debre Berhan, 1979-84.

Source	df	Total area	Total production	Total seed used	Net production	Total yield per ha	Seed used per ha	Net yield per ha
Peasant Association (PA)	3	289.4**	309.7***	8.5***	216.6***	30.0**	.50	22.9
Farmer within PA	61	78.4***	49.6***	1.8***	39.8***	12.3***	.29***	11.0***
Planting year (PY)	5	1.4	150.3***	1.6*	159.8***	65.0***	.39**	65.4***
Number of oxen	2	80.1**	100.9***	2.9**	70.0**	13.8**	.003	14.1**
Fertilizer use (yes/no)	1	17.4	20.9	3.3**	7.6	6.2	.2	4.0
PA x PY	15	29.5*	68.0***	.7	64.7***	10.9***	.15	11.4***
PY x Number of oxen	10	26.7*	43.5**	3.6***	27.9	7.5*	.43***	6.3
Household size	1	25.0	4.5	.8	1.5	.3	.09	.7
TLU excluding oxen[a]	1	19.3	129.4***	1.6	102.2**	21.1**	.01	22.5**
Remainder	137	18.0	18.8	.8	17.3	4.0	.17	4.0

[T]LU = Tropical Livestock Units
*** = P<.01
** = P<.05
* = P<.10

Table 4 Least squares estimates of farm cereal production parameters for Debre Berhan, 1979-1984.

	n	Total area (ha)	Total production (kg)	Total seed used (kg)	Net production (kg)	Total yield (kg/ha)	Seed used (kg/ha)	Net yield (kg/ha)
Overall	237	1.760	1218	256	962	664	144	516
Peasant Association:								
Faji/Bokafia	54	1.941	1357	274	1083	657	139	514
Karafino	64	1.429	995	215	779	660	148	507
Kormargefia	63	1.770	1041	233	808	581	133	444
Melki	56	1.898	1479	302	1177	759	155	600
Planting year:								
1979	41	1.772	1202	304	898	639	165	469
1980	42	1.768	1460	267	1193	818	156	658
1981	40	1.761	974	259	714	545	144	398
1982	36	1.713	1237	250	987	645	143	497
1983	41	1.797	881	249	633	428	134	291
1984	37	1.746	1555	208	1347	909	119	783
Number of oxen:								
Zero	47	1.504	935	213	722	563	144	414
One	68	1.787	1245	255	989	669	145	520
Two or more	122	1.987	1475	300	1175	760	143	613
Fertilizer used:								
Yes	124	1.803	1265	275	990	690	148	537
No	113	1.716	1171	237	933	638	139	495
Household size (adult equivalents)		.055	23	10	13	−6	3	−9
TLU excluding oxen		−.042	−110	−12	−98	−44	1	−46

Cereal production

The least squares analysis of variance for cereal production is summarized in Table 3. The associated least squares estimates are given in Table 4. As indicated in Table 3 the most important influences on total cereal area sown on a farm were PA, the number of oxen owned by a farmer and the effect of individual farmer within his PA. The analysis showed weaker, but significant, interactions between PA and year and between year and number of oxen.

As the total arable land area in each PA is limited, farmer practice with regard to cereal production is best understood by examining the influences on per unit area yields. Seeding rates per ha did not differ across PAs but were most strongly influenced by year, by individual within PA, and by the interaction of year and oxen holding. This suggests that farmers respond by modifying seeding rates each year according to the circumstances encountered at planting time. Farmers in the area maintain stocks of several landraces of each of the major cereals and use these under specific production conditions which is supportive of this hypothesis. Those with no oxen ordinarily gain access to pairs of oxen for cultivation from nearby relatives, whereas farmers with one ox tend to secure a second ox to form a pair from neighbours and not necessarily relatives.

There was a significant influence of fertilizer use on total seed used per farm but no significant effect of fertilizer use on crop yields per ha or on total grain production.

In contrast to McIntire (1983), in his study of a Sahelian farming system, this study found that the level of oxen ownership had a significant effect on both the yield per ha and total area cultivated. Farmers with two or more oxen had total yields per ha 35% greater on average than those farmers owning no oxen. McIntire observed only an area affect in association with donkey ownership.

As regards the total area sown to cereals, the mean area of 1.941 ha for Faji/Bokafia was 36% higher than the 1.429 ha estimated for Karafino, reflecting relatively lower availability of agricultural land per farmer in the latter PA.

Overall, farmers owning two or more oxen cultivated on average 32% more land each year than farmers owning no oxen. Farmers owning one ox cultivated an intermediate land area. Those farmers owning two or more oxen were able to cultivate 1.987 ha per year of cereals in the main cropping season. Farmers in these four PAs sow an estimated average of 1.760 ha to cereals each year with no significant differences across years being observed for the survey period.

The estimated total (gross) cereal production for farmers in the area was 1218 kg per year. Seed usage at planting time accounted for 256 kg or 21% of total production. Total production per farm was highest in Kelki (1479 kg/year) and lowest in Karafino (995 kg/year). The ratio of gross grain production to seed usage ranged from 4.47:1 to 4.95:1.

The increment in total cereal production due to owning one ox rather than no ox is estimated at 310 kg; the increment due to owning the second ox is estimated at 230 kg. Cereal seeding rates varied significantly across years from a minimum of 119 kg/ha in 1984 to a high in the survey period of 165 kg/ha in 1979. The poor harvest in the area in 1983 and market shortages at planting time in 1984 directly reduced both sowing rates per ha and total cereal seed sown in 1984. The 1984 crop year was the best observed in the survey period and resulted in highest yields per ha.

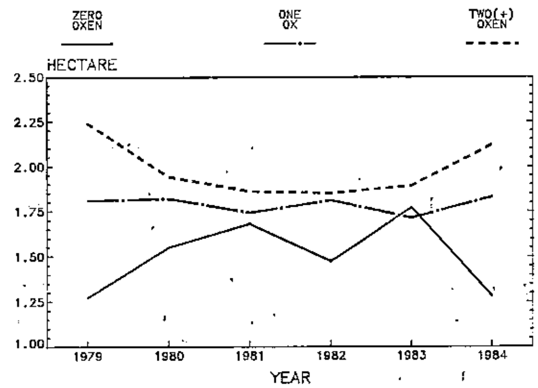

Figure 1 Least squares estimates of farm cereal area (ha) from the interaction of year and level of oxen ownership at Debre Berhan.

Figure 1 graphs the least squares estimates of total cereal area per farm by year for the three levels of oxen ownership specified in the model. The graph shows the positive impact of greater oxen ownership on total farm cereal area. The effect on cereal area cropped of owning a pair as opposed to no oxen was greatest in 1979 when farmers with a pair sowed 77% more land than those without oxen. The differences were also substantial in 1980 (+26%), 1982 (+26%) and 1984 (+65%).

The years with the largest differences were 1979 and 1984. Both these years followed a year when there was a short main growing season. In 1978, the area recorded the lowest rainfall for 20 years (1965-1984), and although there were good rains in January and February of the following year (1979) farmers with two oxen used their oxen to maximise the area they put under crop to make up for the shortfall of 1978/1979. The farmers owning no oxen were severely constrained in the area they cultivated as they had to wait until the farmers with an oxen pair satisfied their own needs. In 1984, farmers suffered from failure of the 1983 season and there were no short rains. Thus in 1979 and 1984 farmers with two oxen ploughed extra land to make up for the previous bad year, and so oxenless farmers were penalised.

Two main factors affect the availability of draught power for oxenless farmers in any year. These are failure of the previous cropping year and the duration of the short rains. If either of these factors applies, the oxenless farmer will cultivate less area as a consequence of deferred access to draught power. In years with effective rains from February to May the soil is more easily ploughed, and the most demanding cultivations can be done before June and individual power shortages can be overcome in a more timely way. Also, early rains produce better pasture growth oxen so are fitter for work in these years. If both these factors apply the negative production effect of limited oxen ownership is compounded.

The successful crop years of 1980 and 1982 together with useful rains in 1981 and 1983 enabled all farmers to cultivate approximately equal areas to cereals irrespective of oxen ownership. However, 1981 and 1983 proved to have poor long rains, and grain yields per ha were substantially reduced (Figure 2).

Table 5 is illustrative of the impact on whole farm net cereal production of increased oxen ownership. For the study period, farmers owning one ox produced on average an estimated 33% (310 kg) more cereals than farmers with no oxen. Farmers with two oxen had a further 18% (230 kg) advantage

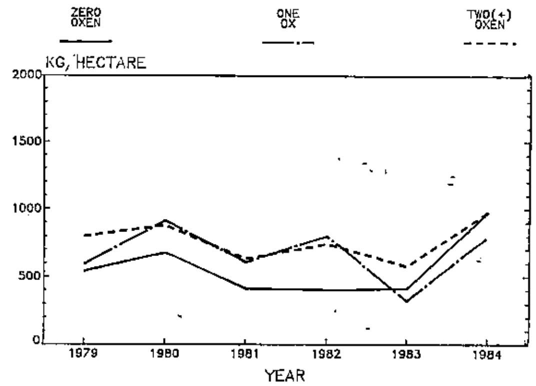

Figure 2 Least squares estimates of cereal yield (kg/ha) from the interaction of level of oxen ownership and year at Debre Berhan.

over farmers with one ox. The Table also shows substantial year to year differences in the relative (dis)advantages of owning additional oxen.

In 1984 farmers with no oxen cultivated 1.28 ha or 72% of their 1983 area. Total population per farm in 1984 was, however, the same for farmers owning no oxen and one ox but both were over 38% less than that produced by farmers with pairs (Table 5). Thus, although farmers with no oxen cultivated substantially less land than farmers with one ox they were able to make up the difference by higher average yields on the land they sowed. Possible explanations for this are that farmers with no oxen sowed cereals only on their most productive land and left poorer fields under fallow and they used more extensively a traditional fertility enhancement practice of soil burning (*gaye*) on these plots (Pers. comm., Abiye Astatke). *Gaye* is a more labour intensive activity than the usual land preparation by oxen.

The total livestock holding by farmers in addition to their oxen was, as noted above, highly significant in relation to total cereal yield and of lesser importance in regard to net farm yield and gross and net yields per ha. Total cereal production on farms was reduced on average by 110 kg for each additional TLU held by farmers. It indicates the need to investigate production issues also at the whole-farm level where the interactions of crop and livestock enterprises can be accounted for.

Table 5 Least squares estimates of total cereal yield from the interaction of level of oxen ownership and year (kg).

	Level of oxen ownership (percent change over lower level)		
Year	Zero	1	2
1979	733	1080(+47)	1792(+ 6)
1980	1016	1691(+66)	1674(− 1)
1981	691	1171(+69)	1060(−10)
1982	880	1431(+63)	1399(− 2)
1983	935	703(−25)	1006(+43)
1984	1355	1392(+ 3)	1918(+38)
Overall	935	1245(+33)	1475(+18)

Table 6 Mean squares (x 100) for farm pulse production parameters for Debre Berhan, 1979-1984.

Source	df	Total area	Total production	Total seed used	Net production	Total yield per ha	Seed used per ha	Net yield per ha
Peasant Association (PA)	3	187.6***	145.9***	4.2***	103.3***	130.9***	.8	127.2***
Farmer within PA	60	28.7***	16.3***	.9***	11.3***	20.1**	2.0***	16.9
Planting year (PY)	5	4.4	9.6	.3	6.9	40.7**	.4	33.8*
Number of oxen	2	.1	5.3	.2	3.4	7.8	.3	7.3
PA x PY	15	6.4	6.4	.2	6.1	22.9	.5	23.9*
PY x Number of oxen	10	8.8	4.4	.1	4.0	12.5	.5	12.6
Household size	1	1.0	.4	.1	.8	.7	.0	.9
TLU excluding oxen	1	4.5	.1	.1	.3	.3	.2	.0
Remainder	128	5.6	6.8	.2	5.8	17.6	.9	15.9

*** = P<.01
** = .01<P<.05
* = .05<P<.1

Table 7 Least squares estimates for farm pulse production parameters for Debre Berhan, 1979-1984.

	n	Total area (ha)	Total production (kg)	Total seed used (kg)	Net production (kg)	Total yield (kg/ha)	Seed used (kg/ha)	Net yield (kg/ha)
Overall	226	.612	396	99	297	659	175	481
Peasant Association:								
Faji/Bokafia	53	.537	317	94	224	547	185	359
Karafino	57	.478	393	83	310	862	187	671
Kormargefia	60	.539	248	78	170	507	169	336
Melki	56	.894	626	140	486	721	161	557
Planting year:								
1979	37	.564	432	110	322	818	197	617
1980	40	.596	494	107	386	882	194	683
1981	38	.653	430	112	318	686	177	504
1982	35	.686	406	102	304	517	156	357
1983	39	.618	339	88	252	560	155	404
1984	37	.553	275	72	203	492	173	318
Number of oxen:								
Zero	40	.603	318	84	234	599	158	439
One	67	.617	418	100	318	644	187	454
Two or more	119	.615	451	111	340	734	181	549
Household size (adult equivalents)		.012	7	−3	10	10	−1	
TLU excluding oxen		.022	−3	3	−5	−6	−4	11
								−2

In summary, the most important influences on total cereal production on any farm in the study area were the level of oxen ownership, year of cropping and peasant association. The effect of the individual farmer within a PA was significant, highlighting the differences among farmers in their performance as cereal farmers. The results suggest that the nominal labour supply per farm is not a limiting factor on cereal production. Fertilizer use in the area is sporadic and low and is not applied at an equal rate to all plots within any year. The analysis showed fertilizer usage to have a significant and positive effect only on the total amount of seed used per farm.

Pulse production

The least squares analysis of variance and the least squares estimates for the pulse production data are summarized in Tables 6 and 7 respectively. They highlight the major differences in the factors influencing pulse production as compared with cereal production at the whole farm level. The total area sown to pulses was highly significantly influenced by PA, and by farmer within PA. Oxen ownership did not have a significant influence on the pulse production parameters examined. This reflects both the greater importance farmers place on cereal production and the lower per unit area cultivation needs of pulses.

Pulse yields per ha are influenced significantly by PA, and year of planting. Seeding rate is only and highly affected by the farmer within the PA.

Overall, a total .612 ha is sown to pulses by farmers in the survey area. Farmers in Melki sow an estimated .894 ha each year, 87% more than farmers in Karafino. Of the four PAs studied, Melki has the smallest area subject to frost, thus favouring pulse production in this PA. For the survey period farmers sowed the greatest area of .686 ha to pulses in 1982 and least in 1984 when they grew .553 ha of pulses. The total area sown to pulses each year is more variable than the area sown to cereals.

Total pulse production per farm ranges from 248 kg in Kormargefia to 626 kg in Melki. These differences between PAs arise due to a combination of yield differences per ha and areas sown.

Thus the main influences on pulse production arose from the differences in cropping environment as regards frost risk and differences between farmers within a PA.

As the annual estimates of total cereal and pulse areas were derived independently they can be added to give an estimate of total cropped area for each year. In the survey period farmers, on average, sowed the smallest area in 1984 (2.30 ha) and the largest area in 1983 (2.42 ha), a difference of only 5%.

Conclusions

Some factors influencing crop production in a representative smallholder farming area of the Ethiopian highlands have been analysed. The results highlight the impact of ecological diversity on both cereal and pulse production. Adjacent farming locales were shown to have significantly different agricultural productivities. Cereals were shown to be more important than pulses in the study area. Farmers apply their scarce human and animal labour resources to cereal production in preference to pulses.

Ethiopian farmers have an ancient tradition of using oxen for cultivation, but oxen ownership is not uniform across farmers. The analysis showed the critical consequences on total farm production of not owning oxen, which is reflected in area cultivated and in yields per unit area. Farmers owning fewer oxen cultivate less land, and have lower total grain yields. They are especially disadvantaged when a short cultivation period follows a poor main crop season and when the early short rains fall.

The importance of owning at least one ox has been highlighted. This indicates that at least for this farming system, and perhaps others in Ethiopia, credit schemes to improve draught power capacity at the individual farm level should in the first instance be directed towards those farmers without oxen to increase their ownership to one ox.

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43 Intercropping – Its Future as a Cropping System in the Drought Prone Semi-arid Tropics of West Africa

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Abstract Traditional intercropping practices dominate the food production systems in the West African semi-arid tropics (SATWA). Although intercrops cover more than 75% of the areas on which food crops are grown, agricultural research efforts have been focused on sole crop systems. Recently, researchers have begun to examine the role of traditional intercropping practices in increasing food crop production. The authors argue that intercropping systems will contribute to stabilizing and intensifying food grain production, as well as meet the product goals of the traditional farmers, under the severe conditions of the semi-arid regions of West Africa.

This paper examines the place of the intercrop in traditional agriculture in SATWA. The reasons for its wide acceptance by farmers in a drought prone region are discussed. The production advantages found by research are described.

The cropping systems research needs in West Africa are discussed with particular reference to understanding and developing intercropping systems that perform well in this severe environment. Research approaches to developing intercropping systems that are productive, stable, and acceptable to the resource poor farmers are discussed. Stress is placed on intercropping systems that are practical.

Introduction

Intercropping – the growing of two or more crops simultaneously in the same field (Andrews and Kassam 1976) – is the dominant practice used by smallholder farmers in the drought prone, semi-arid tropics of West Africa (SATWA). Nonetheless, until recently, agricultural research efforts have been largely confined to improving sole crop performance.

Improved management strategies for higher and more stable food production in SATWA must consider the advantages of these traditional intercropping systems and, inherent in them, the production goals of the farmer. This paper examines the place of intercropping in traditional agriculture systems and the attributes of intercropping systems that will enable them to play an important role in meeting the present and future food needs of this drought-prone region. A particular emphasis is given to two common intercropping systems: maize/millet and millet/cowpea.

Intercropping in Traditional Agriculture

Intercrops cover over 75% of the cultivated area in the West African tropics (Steiner 1984). In northern Nigeria, Norman (1974) found that intercrops were used on 83% of the cultivated area. Similar figures were reported in Niger (Swinton *et al.* 1985) and Burkina Faso (Matlon and Bonkian 1980; McIntire 1982; Sawadogo and Kaboré 1985). For as long as smallholder agriculture continues to dominate the region, intercropping is likely to maintain its status as the predominant cropping system used for food production.

The number of distinct crop combinations can be large. Norman (1974) recorded 156 different associations in northern Nigeria. Nonetheless, 40% of the area was devoted to 2-crop mixtures such as millet with sorghum and millet with cowpeas. Comparing the findings of Norman (1974) in Nigeria with those of Swinton, Numa and Samba (1985) in Niger, it is apparent that the variety of crop combinations and the intensity of the intercropping systems decreases with the annual rainfall, indicating a certain agroclimatic dependence of the potential diversity of intercropping, as well as, its intensity.

Farmers give four principal reasons for intercropping: (1) tradition, (2) the need to maximize the return from a factor which is most limiting, such as labour, (3) the need for security and (4) the beneficial effect of legumes on other crops (Norman 1977). Abalu (1977) concluded that the farmers of northern Nigeria used intercropping to diversity activities and as an insurance against biological and economic risks, a finding supported by results from Niger (Swinton et al. 1985). Intercropping normally maximizes returns per man-hour, thereby making efficient use of the human resource (Norman 1977; Matlon 1985; Swinton et al. 1985).

Some Attributes of Intercropping Systems

Overall production advantages

Research on intercropping systems is basically a recent phenomena for the region (Fussell and Serafini 1985), although Baker (1981) points out that in Nigeria experiments on intercopping date back to the early twenties. Where intercropping systems have been studied in West Africa the findings, as a whole, indicate that there are yield advantages over the components crops grown as sole crops (Fussell and Serafini 1985). While yield advantages of 20-30% are the most common, total yield advantages range from 10-100%. This complementarity has been demonstrated for the common cereal/legume (eg. millet/cowpea, sorghum/cowpea, cereal/groundnuts) and cereal/cereal (eg. maize/millet, maize/sorghum, and millet/sorghum) associations (Fussell and Serafini 1985).

For example, at the ICRISAT Sahelian Center (ISC) in western Niger, the combination of cowpea with millet has resulted in production advantages of 10-40% over the last four years (Table 1). Similar studies on this system in Mali over a period of three years, a number of management systems and locations, have shown advantages up to 100% (Table 1).

The combination maize/millet was studied over a number of management systems, locations and seasons in Mali. Intercropping advantages ranged up to 100% (Table 1).

Resource use differences

The complementarity of crops grown in association results from the spatial and temporal differences which exist in their growth habits (Willey 1979a). Generalized growth patterns of intercropping systems that result in spatial and temporal complementarity are represented in Figure 1a and Figure 1b, respectively. Temporal differences occur when crops make their major

Table 1 Intercropping effect from trial means of factorial experiments which included other management factors such as intercrop density, fertility, planting date and harvest time of intercrop.

Year	Type of experiment	Location	Rainfall (mm)	Cowpea hay/ maize grain (kg/ha)	Millett grain (kg/ha)	Land equivalent ratios: cowpea	millet	total
Millet/cowpea intercrop:								
1982	Density x variety x intercrop proportion	Sadoré, Niger	372	318	277	0.58	0.69	1.27
1983	Intercrop proportion x rotations	Sadoré, Niger	599	768	385	0.48	0.69	1.17
1984	Intercrop proportion x rotations	Sadoré, Niger	216	22	435	0.09	1.16	1.25
1985	Intercrop proportion x rotations	Sadoré, Niger	495	734	648	0.48	0.72	1.20
1985	Variety x intercrop	Sadoré, Niger	495	360	921	0.31	0.93	1.24
				(261)**		(0.50)		(1.43)
1979	Density x intercrop	Multilocation, Mali	NA	158	854	0.96	0.21	1.17
1980	Density x intercrop	Multi-location, Mali	NA	1460	980	1.04	0.50	1.54
1981	Intercrop harvesting schedule	Multi-location, Mali	NA	4050*	800	1.12	0.83	1.95
Maize/millet intercrop:								
1982	Intercropping study	Cinzana, Mali	579	2010	840	1.12	0.57	1.69
1982	Intercropping study	Sikasso, Mali	1046	1800	880	1.04	1.06	2.10
1983	Planting date x intercropping	Sikasso, Mali	756	590	1920	0.29	0.82	1.11

* Hay yields are fresh weights.
** Cowpea grain yields

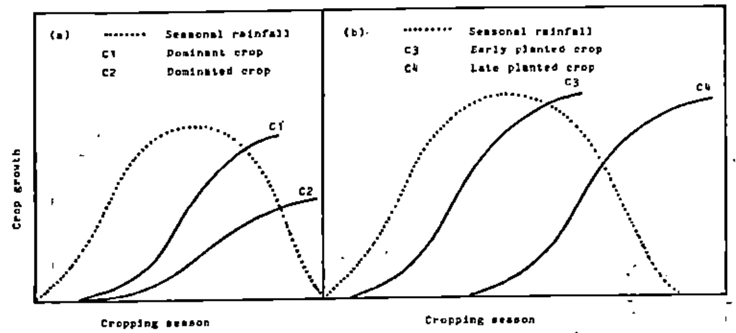

Figure 1 Graphical presentation of crop growth patterns which result in mainly (a) spatial and (b) temporal complementarity.

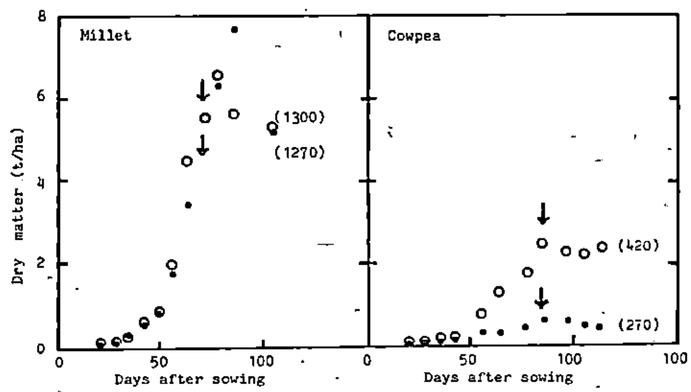

Figure 2 Dry matter accumulation in a millet/cowpea intercrop (●) compared with sole crops (○) at the ICRISAT Sahelian Center, Sadoré, Niger, 1985 cropping season (grain yield in brackets – kg/ha, ↓ time to flowering).

demands on resources at different times, and thus exploit the resource base more fully over time (Willey 1979a). Differences in crop resource use over time generally result in the more important yield advantages with intercropping production systems.

In the maize/millet intercropping system, a 110-120 day maize is planted simultaneously with a qualitative photoperiod sensitive 180-day millet. The maize makes most of its demands on the available resources while the millet is still in the vegetative stage and matures before the millet flowers. Millet is very resilient to stress in the vegetative stage. Once the maize is mature, it quickly overcomes the effects of competition from the maize and the millet is able to produce a near-normal yield (Table 1).

Spatial complementarity occurs when the associated crops may make more efficient use of resources over space. Millet intercropped with late season cowpea combines both temporal and spatial effects. A substantial amount of the cowpea growth does occur at the same time as the millet (Figure 2). During this period, the cowpeas may be managed by planting

Table 2 Mean intercropping effect from a factorial experiment in 1984 and 1985 at the ICRISAT Sahelian Center, Niger.

Year	Cropping system	Millet grain yield (kg/ha)	Cowpea hay yield (kg/ha)	Maximum total radiation interception (%)	Seasonal moisture use (mm)
1984					
	Sole millet	335	–	36.5	223
	Intercropped millet	273	14	33.9	
	SE	±15.8	–	±1.01	
			–	48.0	352
		925	653	55.8	389
		±22.9	–	±0.78	±3.3

them after the millet so that they do not limit millet growth. The taller cereal is able to shade and effectively dominate the cowpeas. If the season is sufficiently long, as the millet matures, the cowpea will go on to make a reasonable forage crop, as well as some grain. If the rains end early, the cowpea will be harvested as forage, before or after the millet. When planted simultaneously, manipulating the spatial and temporal differences of the two crops by harvesting these forage-type cowpeas early, maximizes yield advantages (Serafini 1985). This management strategy results in optimum cowpea forage yields and millet grain yields that are the same or superior to the sole crop yields.

Spatial and temporal complementarity may result in small to large increases in resource use. For example, in a millet/cowpea intercrop grown at the ISC in 1985 (rainfall = 520mm, long term average rainfall = 560mm), only a small increase in resource use occurred. Light was increased by 16% and soil moisture use by 11% (Table 2). Similar increases over the component sole crop resource use was reported for this intercropping system in an earlier experiment (Fussell 1985). The total output of the intercrop system was increased with the extra cowpea hay production while millet yields were only slightly reduced (12%). These yield advantages occurred because the light- and water-use efficiencies of the system were increased. In another experiment in the same year and location, intercropping a full millet stand with up to 10000 hills/ha of cowpea had little effect on millet yields (Figure 3) and resulted in substantial cowpea forage yields.

Stability

Improved food production in SATWA should rely on management practices that increase yields, when this is possible, while improving the stability of production in both good and poor rainfall years. Production can be stabilized through a reduction in yield variation from year-to-year and by insuring higher production from the good years that provide stocks that may be used in the poor years.

Yield stability has been proposed as a major advantage of intercropping systems (Willey 1979a, b; Steiner 1984). For example, stability may result from one crop compensating for the poor performance of the other crop.

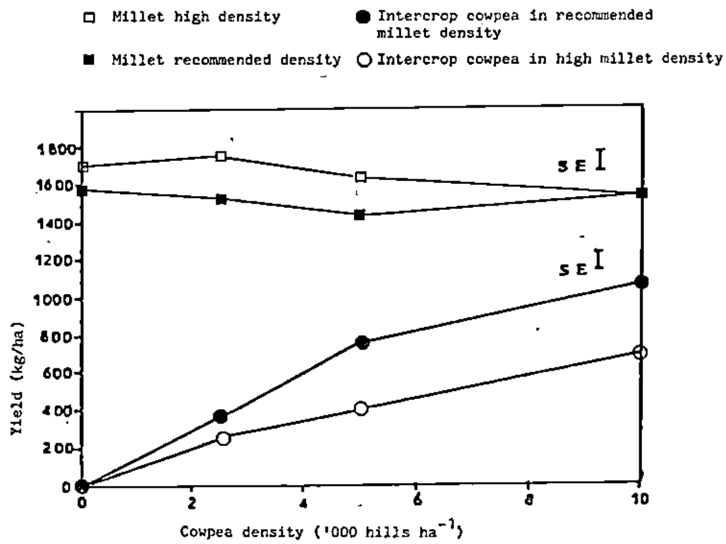

Figure 3 Millet grain yield and cowpea hay responses in a millet/cowpea intercropping system at three cowpea densities ISC, Niger, rainy season 1985. (Source: Fussell et al. 1986).

When one component crop suffers from stress (drought, disease, insect attack), the loss in vigour is compensated for by the other crop(s). Only Baker (1980) has compared the relative stability of intercropping and sole cropping systems in SATWA. Using the analysis of Finlay and Wilkinson (1963), he found no difference between the yield stability of intercrops (groundnut/cereals) over sole crops in northern Nigeria. Nonetheless, when he compared the probabilities of failure, based on a 'disaster' level of income, intercropping systems were found to be more stable.

Examining the combined results of a number of experiments for maize/millet and millet/cowpea intercropping systems, it is apparent that the yield advantages are relatively consistent over time and rainfall regimes (Table 1). This suggests the possibility of improved performance and stability of intercropping over the mono-cropping systems.

If drought is one of the major problems for the food production systems of SATWA, the capacity of a cropping system to consistently give some yield even in the drier years, is an important contribution to these systems. Temporal differences in crop resource use may be particularly important in drought periods, because they minimize the probability that all components will be equally affected if drought stress occurs (Wiley *et al.* 1985).

For example, if drought stress occurs towards the end of the cropping season, the production of later planted intercrops may be reduced but earlier planted crops will have their production assured (Figure 1b). Conversely, if drought stress occurred in the first half of the earlier planted crop, the growth of the later planted crop may be totally suppressed. The reduced growth and competition from the later planted crop, may result in a reduction in yield of the early planted crop when compared to its sole crop. This situation occurred in Niger in 1984 when rainfall was very low throughout the season. The growth of the cowpea planted after the millet was very low, but the millet yields were only reduced by 20% (Table 2). This may contribute to traditional intercropping systems capacities to produce some yield from the principal component in all but the harshest years.

Temporal complementarity in crop development has the greatest potential to be exploited and enhanced in improved intercropping systems for drought-prone areas. Exploitative crop associations may not lower total yields in low rainfall years, and will substantially increase them when there is sufficient rainfall to more fully exploit the rest of the resource base. These attributes will enable intercropping to continue to be a viable production system alternative in SATWA.

Research Needs and Approaches

Compared to the research in SATWA on mono-cropping systems, there has been few and sporadic research efforts concerning intercropping systems. Research needs are plentiful if improved intercropping systems are to stabilize and increase food production in the region. The choice of research priorities and perspectives needs to be chosen carefully if research is to have an impact at the farm level.

There are only a few instances where research resulted in practices that have been tested at or extended to the farm level because of the lack of a consistent research effort in the past. In Mali, an improved maize/millet intercropping system is in the process of being extended (Anonymous 1985). Cotton/maize intercropping has been tested at the farm level in Nigeria (Bbuyemusoke *et al.* 1985). Both these systems are traditional intercropping systems, with higher levels of inputs and management.

This experience would indicate that researchers should first seek to improve management practices for traditional intercropping systems that will increase the output of the major staple crop products of the region. Despite the fact that fertility management has been shown to be necessary for intensifying intercropping systems (Serafini 1985), there are few fertilizer recommendations for these intercropping systems. Research on the fertilizer needs of traditional intercropping systems is a priority because poor fertility, particularly low phosphorous levels, is the major limitation to increased yields in SATWA (Fussell *et al.* 1986). Nonetheless, the research emphasis on improving traditional cropping systems should not preclude the possibility of looking at new intercropping systems, such as very early maturing cowpea with late maturing millet.

There are very few reports on the water-use of intercropping systems. This is surprising considering the role drought plays in the region. A better understanding of the water-use characteristics of the major intercropping systems would permit a probability-based agroclimatic zonation, as is done with sole crops, whereby the various intercropping systems could be placed in areas where they would have a higher probability of being successful.

Conclusions

Production and water-use efficiency may be improved by the use of intercropping systems. The associated crops' contrasting growth habits permit them to better exploit time, rainfall and other resources. This leads the authors to conclude that intercropping systems have not only a current but also a future role to play in better management strategies for higher and more stable agricultural production in the region.

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44 An Approach to Increasing Crop Productivity under Drought Conditions. A Case of Northern Benin.

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Abstract The semi-arid areas of Africa are characterised by unreliable and unpredictable rainfall, a short rainfall period which requires that all farming activities are completed within a limited period of three to five months. The situation is further aggravated by poor soils which are also in certain cases supposed to support large livestock numbers.

An integrated approach which incorporates crop, livestock and trees while recycling manure, organic matter, nitrogen and other mineral components for the improvement of soil structure and fertility is being developed. The related socio-economic aspects and their overall implementational strategy are discussed in terms of agricultural development in northern Benin.

Introduction

The semi-arid areas of Africa have, in recent years, suffered from frequent drought in addition to insufficient soil moisture due to short, erratic and/or unpredictable rainfall. Analysis of data for all West African countries suggest that from 1960, through 1970s, the annual rainfall declined by 40 to 30% below the long-term average for that zone. For example African countries like Ethiopia, Burkina Faso, Mali and Ghana had food and livestock feed shortages in the early 1980s. In instances where severe moisture stress is coupled with a deteriorating soil resource base, many of the traditional agricultural production systems become extremely unproductive and risky.

The aim of this paper is to examine an integrated systems approach that incorporates crop, livestock and trees under drought conditions, while maintaining an ecological balance in semi-arid areas. More specifically, this paper describes a case study of Northern Benin undertaken with the following objectives

i To discuss the agroclimatic, environmental and socioeconomic characteristics of a semi-arid area.
ii To review production systems being practised and their related production constraints present in the area, and
iii To assess technological options available for an integrated systems approach incorporating crop, livestock and trees thus recycling organic matter and other soil nutrients.

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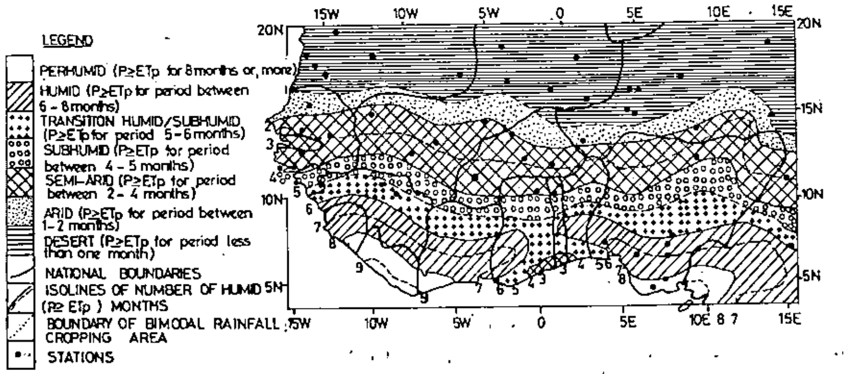

Figure 1 Generalized agroclimatic map of West Africa (Source: T.L. Lawson, IITA, 1979)

Agroclimatic Characteristics of a Semi-arid area

According to agroclimatic criteria, the semi-arid tropics are defined as those areas where precipitation exceeds potential evapotranspiration for a period of 2 to 4 months annually. This agroclimatic definition is related to the concept of water-balance and the period of moisture availability for crop production and it is based on Franguin's method of interpretation of rainfall and potential evapotranspiration curves.

By this definition, the large part of Africa, stretching from West, Central, Eastern to Southern is semi-arid. For instance in West Africa, agroclimatic zones change rapidly from humid, and sub-humid to semi-arid and Sahelian conditions, from south to north (see Figure 1) and the semi-arid and arid zones cover more than one third of the land mass. The West African semi-arid zone includes large portions of Benin, Cape Verde, Senegal, Mali, Burkina Faso, Niger and the Northern parts of Guinea, Ivory Coast, Ghana, Togo, Nigeria and extends to Tchad and Northern Cameroon.

In this agroclimatic zone the rains begin gradually South to North in May/June and end abruptly in October or September. Thus the cropping season begins from May to October in the South, and from late June to September in the North, giving a short agricultural season of only 4 or 6 months in a year in Sahelian and Sudan Savanna zones respectively. Therefore farmers without supplementary irrigation facilities must concentrate all their agricultural production activities in this very short period of 4 to 6 months.

From Sudan Savanna (in the South) to Sahelian (in the North) therefore, a shift from long to shorter cycle crop varieties of maize, sorghum and upland rice and/or to more drought tolerant crops like millets, cowpeas and fonio is observed.

Although high temperatures and solar radiation during the season are normally conducive to rapid plant growth, these tend to also increase water requirements for crops and high evaporation reduces available soil water. Moreover, when a dry spell lasts for more than two weeks, at critical periods of crop growth it may drastically reduce soil water and cause severe moisture stress to the crop.

Agroclimatic Characteristics of Northern Benin

Northern Benin consists of Borgou and Atacora provinces stretching over three agroclimatic zones namely Sahel Savanna in the extreme North with mean annual rainfall of 400-600mm, (b) Sudan Savanna (600-800mm) in the mid-belt and (c) the Northern Guinea Savanna (800 and above mm) in the South.

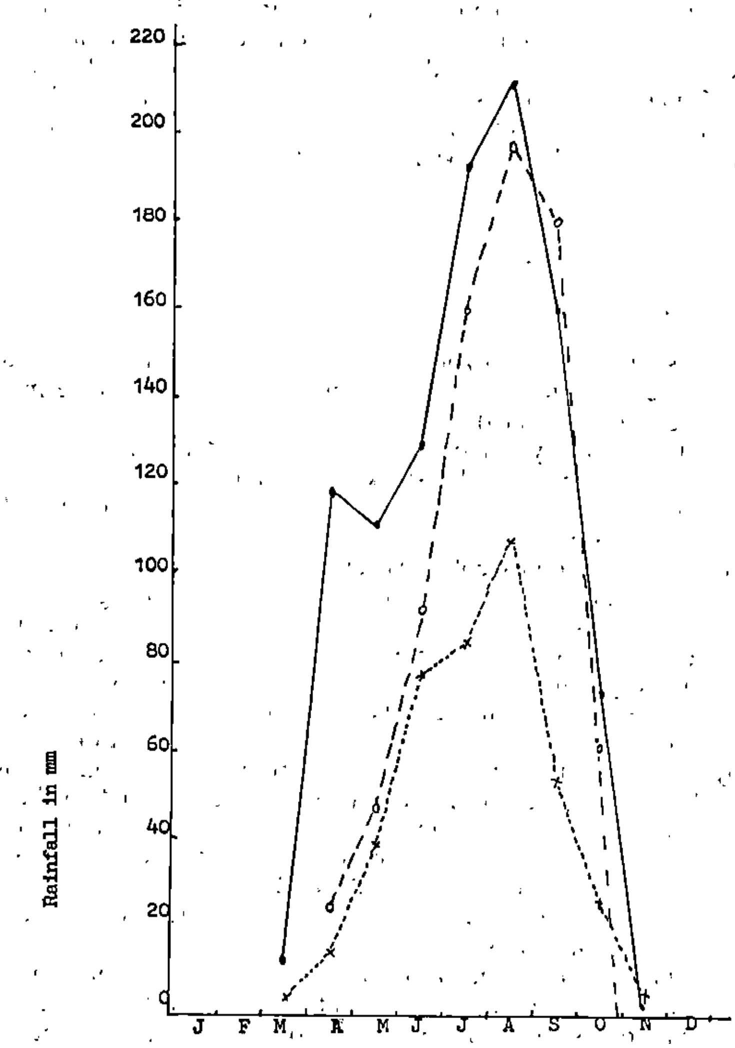

Figure 2 Mean annual rainfall for North Benin between 1975-1982

x----x Sahelian savanna

O---O Sudan savanna

●—● Northern Guinea savanna

The rainfall distribution in the Sahelian savanna starts in April but does not stabilize till the end of May and increasing gradually with a peak of about 108mm in August and drops sharply cutting off at the end of October (see Figure 2).

In the Sudan Savanna, rainfall tends to be late and erratic, beginning in April with a peak of about 196mm in August and cuts off by end of October. In the Northern Guinea savanna, rainfall starts at the beginning of April, stabilizes in May and increases gradually to a peak of about 211mm in August and cuts off by end of October.

Analysis of rainfall data for Northern Benin between 1975-1982 gives a mean annual rainfall of 412mm for the Sahelian savanna, 760mm for the Sudan savanna and 1014.25mm for the Northern Guinea savanna. When these rainfall figures are compared with the long-term average of 900mm for the Sahelian zone, 1000mm for the Sudan savanna zone, 1100mm for the Northern Guinea savanna it is suggested that annual rainfall has declined in recent years by as much as 50% in the Sahelian zone and 25 to 10% in the Sudan and Northern Guinea savanna respectively.

Existing Production Systems

Cropping Systems

Moving across the ecological zone of Northern Benin, the existing farming systems can be characterized by (a) cropping systems consisting mostly of intercropping cereal crops (b) shifting cultivation where exhausted lands are left fallow for 3 to 4 years before being cropped again and (c) a high interaction between crop and livestock production.

In the Guinea savanna zone, maize-sorghum intercrop is grown by 75% of the farmers, followed by cotton which is grown by 49%, yams 44%, sorghum 40%, groundnuts 35%, cassava 33% and cowpeas 31% of the farmers. Millets and yams intercropped with beans are also grown by 22 to 18% of the farmers see Table 1. In the Sudan Savanna, cotton is the dominant crop, followed by cassava, groundnuts, millets, maize intercropped with sorghum and beans being grown by respectively 85, 64, 57, and 35% of the farmers. In the Sahelian zone at the extreme North the important crops in the farming systems are millets and cotton each being grown by 76% of the farmers, sorghum and groundnuts each grown by 69% farmers followed by sorghum intercropped with maize millets or beans.

In the whole region the average farm size is 7.46ha per family with 6.5ha under crop and 0.9ha under fallow. In other words, in the Sahelian savanna zone, an average farm family plants 1.36ha (22% of the farm) to sorghum, 1.06ha (17% of farm) to millets, 0.71ha (12% of farm) to cotton and 0.5ha (8% of farm) to groundnuts.

A farm family in the Sudan savanna plants 3.84ha (49% of farm size) to cotton, 0.64ha (8% of farm) to maize intercropped with sorghum, 0.39ha (5% of farm) to cassava and 0.37ha (5% of farm) to groundnuts. In the Northern Guinea savanna, an average family plants 1.66ha (17% of farm) to maize intercropped with sorghum, 1.58ha (16% of farm) to cotton, 0.9ha (9.4% of farm) to maize/yams/beans and 0.77ha (8% of farm) to yams.

Cropping Calender

In the Sahelian zone, cropping activities start with soil preparation and planting of food crops done in May, whereas cotton is planted in early June. In Sudan savanna, soil preparation and planting are done in May/June depending on the on-set of rains. In the Northern Guinea savanna, soil preparation is done in April and planting of crops in May again depending on how the rains stabilize.

However; in the three agroclimatic zones, the optimal planting date is around end of May, but not later than first week of June.

Agronomic practices used by farmers

There are some agronomic practices and small farm equipments recommended by extention agents for cotton, maize and groundnuts. Cotton production in the area is supported by a strong extension service and economic incentives including free cotton seeds, credit facilities for ox-pough, fertilizers and insecticides, on-farm purchase and transportation of cotton lint at harvest. Most farmers in the area have therefore adopted greater portions of the cotton recommendations, namely improved cotton seed varieties, fertilizers, insecticide application of five to six sprayings and two to three weedings. Whereas in cases of maize and groundnuts, farmers mainly picked up improved varieties and ignored the other recommendations for food crops.

The most common agronomic practices used by farmers for food crop production are slash and burn, plough or dig the land, plant with fingers on the flat or on ridges and on mounds for yams and cassava, hand weed with a traditional hoe.

In the Sahelian savanna zone, sorghum is often planted in compound farms around the homes or in bottom valleys where soil fertility levels are higher. Millets and maize are planted in valleys and bottom lands, while cotton is planted on plateaux since it must receive fertilizer application. In both Sudan and Northern Guinea savanna zones most food crops are planted on plateaux.

For land clearing, most of the farmers in the Sahelian zone, use light clearing which implies that there is very little vegetation to slash and burn; while both in the Sudan and Northern Guinea savanna, farmers slash or cut bush with trees and burn. Wide scale bush burning during the dry season is thus a common practice in the area.

Soil preparation in the Sahelian zone is mostly done by oxen, where 84% of the farmers use ox-plough for millets, 61% use it for cotton, groundnuts and sorghum (see table 1 column four). In the Sudan savanna, 42% of the farmers use ox-plough for groundnuts, 36% for cotton and 14% use ox-pough for maize/sorghum and millets. In the Northern Guinea savanna, ox-plough is very rarely used. Only 16% of the farmers use ox-plough for cotton, while 10% use it for maize/sorghum and groundnuts.

The most common methods used for land preparation in the Northern Guinea savanna, is to dig with a hoe, make ridges especially for cotton and groundnuts or make mounds for yams and cassava.

Planting in lines on flat is mostly used in both the Sahelian and Northern Guinea savanna and rarely used in Sudan savanna, whereas planting on ridges is more popular in Sudan and Northern Guinea savanna. Farmers in the Sahelian savanna zone frequently plant with their fingers, whereas farmers in the other two zones plant in pocket holes with a hoe, a stick, or "roullete" a rotating castor wheel.

Livestock production

Livestock plays an important role in the production systems in Northern Benin. In the Sahelian, Sudan and Guinea savanna zones, 54, 50 and 60 percent of the farmers keep a stock of cattle, goats and sheep. The interaction between crop and livestock production is becoming increasingly significant due to the use of animal traction. In the Sahelian savanna zones practically every farmer has oxen for draught power, while 78 and 12 per cent of the farmers in the Sudan and Guinea savanna respectively have animal traction, giving an average of 39% of the farmers who use animal traction in the region. It is noteworthy that although there are more cattle in the Sahelian and Sudan savanna zones, most of the cattle belong to nomads who do little or no farming and have probably moved there in search of suitable grazing pasture.

Feeding of livestock during the rainy season is usually by grazing. During the dry season when most vegetation is dried up or burnt down by bush fires, feeding of livestock becomes a problem. In the Sahelian Savanna, livestock is moved further south in search of grazing grounds or use tree leaves and crop residues to feed their livestock.

In the Sudan savanna, 57% of the livestock is grazed in wet bottom lands and 20% are moved further south.

In the Northern Guinea savanna, about 20% of farmers graze their livestock in wet bottom lands, 10% move their livestock south-wards and

Table 1 Percentage of farmers within each zone growing various crop enterprises and those using ox-plough

Zone	Crops cultivated and cropping	% of farmers growing crops	% of farmers using ox-plough
Guinea Savanna	Maize (sorghum intercrop)	75	10
	Cotton	49	16
	Yams	44	
	Sorghum	40	8
	Groundnuts	35	10
	Cassava	33	
	Cowpeas	31	
	Millet/yam/bean intercrops	18 to 22	
Sudan Savanna	Cotton	85	36
	Cassava	64	
	Groundnuts	57	42
	Maize/sorghum	35	14
Sahelian	Millet	76	84
	Cotton	76	61
	Sorghum	69	61
	Groundnuts	69	61
	Sorghum/maize	8	15
	Sorghum/millet	7	
	Sorghum/beans	7	

32% use tree leaves or inedible parts of crops like peels to feed the livestock.

Efficient use of farm Resources

Apart from land, other important farm resources are family labour, animal traction and ox-plough. Cash income for purchased inputs including small farm tools, fertilizers and seeds are also important.

In Northern Benin, the size of a farm family ranges from 2 to 19 with an average of 10 persons. Of these 51% are children between 0 and 15 years old and 49% are adults with ages between 16 and 72 years old. The availability of family labour for farm work is 4.94, 5.23 and 2.69 man-units per farm family in Guinea, Sudan and Sahelian zones respectively.

Table 2 shows farmer's farm resource use in northern Benin, and that a farmer in the Sahelian zone has a pair of oxen and uses up to 66.8 hours of ox-plough.

In Sudan savanna, a farmer has 3 oxen for draught power and uses up to 78.9 hours of ox-plough. While most farmers in Northern Guinea savanna do not have their own oxen a farmer in the Guinea savanna has access to at least 1 oxen and uses about 37 hours of ox-plough.

Considering crop production activities during the agricultural season, a farmer in Sahelian savanna zone spends a total family and non-family labour of 485.8 man-days of which 55.8 are used for land clearing, 56 for planting, 138 for weeding, and 188 man-days for harvesting. The farmers in the Sudan savanna spend 806.95 man-days for all crop production activities compared to farmers in the Northern Guinea savanna who spend 917.8 man-days.

Table 2 Farmer's resource use in Northern Benin

Item	Sahel Savanna	Sudan Savanna	Northern Guinea Savanna
Farm size ha	4.32	6.9	8.89
Animal traction	2.4	3	0.4
Use of ox-plough for all crops (hrs)	66.8	78.9	37.2
Family labour supply man-units	2.69	5.23	4.94
Total family and non-family labour man-days			
Used for all crops for	485.8	806.95	917.8
– Land clearing	55.8	190	191
– Soil preparation	37	39.95	51
– Ridging	6	69	49.8
– Mounding	5	49	37
– Planting	56	99	89
– Weeding	138	160	240
– Harvesting	188	200	260
Cost of farm input CFA/Year			
– Hire or cost of oxen + ox-plough	22.455	13.136	8.906
– Small farm tools	723	1.879	11.73
– Fertilizers for cotton	13.500	87.107	23.377
– Seeds	730	6.071	2.129

The most labour demanding crop production operation in each of the agroclimatic zones is harvesting, followed by weeding, soil preparation and planting. The labour requirement for soil preparation, ridging, mounding and planting are 104, 256.95 and 226 man-days in Sahelian, Sudan and Northern Guinea savanna respectively.

If the availability of family labour in man-units is taken as 2.69, 5.23 and 4.94 for Sahelian, Sudan and Northern Guinea savanna respectively and a working week is 6 days, the farm family in Sahelian savanna needs 7 weeks to complete the crop production activities up to planting. Whereas the family in Sudan savanna or Northern Guinea savanna requires over 8 weeks. This analysis implies that if the last planting date is the first week of June, then soil preparation and planting activities should be started in March, which is impracticable since March is still in the dry season. This analysis also suggests that whenever the rains begin late and/or if there is a prolonged dry spell, farmers in those zones face a high risk of late planting.

The cost of farm inputs (Table 2) suggest that apart from ox-plough and cotton fertilizers, farmers in that area have limited use of purchased farm inputs.

In order to examine the relative importance of farm resources that are available to farmers in Northern Benin, the principal component analysis was used to analyse the survey data. In this analysis, related farm resources were grouped together and each formed a factor, thus giving 1, 2 and 3 factors.

Groupings in each factor were selected on the basis of size of their respective factor loading. A factor loading of any variable was between 1 and −1. The significance of each factor was determined by whether or not its latent root, the Eigenvalue was greater than Unity. If a variable had a factor loading, closer to either 1 or −1, then it was considered significant. But if its factor loading was closer to zero, then the variable was not significant. Factors 1 and 2 whose Eigenvalues were 2.84 and 1.62 respectively and which accounted for 47 and 27% of the variance were significant (Table 3).

In Table 3, the most important set of farm resources were land, total farm labour and labour inputs for critical farm operations (soil preparation, planting and weeding) with their respective factor loadings of −0.45, −0.560 and −0.550. Next in importance were the use of ox-plough and animal traction with factor loadings of −0.673 and −0.634 respectively, followed by

Table 3 Relative importance of farm resources used by farmers

1. *Factors*	1	2	3
Eigenvalues	2.84	1.62	0.7
Percentage of variance due to factors	47.33	27.07	11.66
2. *Factor Loadings*			
Hectares	−0.450	0.367	−0.068
Family labour units	−0.401	0.003	(−0.842)
Total farm labour	(−0.560)	−0.096	0.342
Labour for critical farm operations	(−0.550)	−0.096	0.368
Hire or cost of ox-plough	0.002	(−0.673)	−0.055
Animal traction	0.145	(−0.634)	0.176

availability of family labour. It should be noted that the negative signs of the factor loadings suggest that the resources were not being efficiently used.

Farmer's Production Constraints

An integrated systems approach takes as its starting point, the view that when utilising the available resources and operating a diversified production system rural farmers face various physical, biological and/or socioeconomic constraints. For a given level of resource base, the farmer's most limiting production constraints may be alleviated by (a) reorganisation of his production system, (b) improving his technical knowhow (c) initiating some technological change and/or (d) providing him with infrastructural facilities.

Three approaches were used to examine the farmer's production constraints in Northern Benin. Firstly to interact with farmers throughout the agricultural season, asking them to point out their priorities and the production constraints on their fields. Secondly by examining crop performances and factors that determine yield and crop losses and thirdly by collecting data on various aspects of crop and livestock production and analyzing these to derive the most limiting production constraints.

Farmer's declared priorities and crop production constraints

In the course of examining the production systems of Northern Benin, farmers were asked to rank their first and second priorities, their major preferred food crops and major constraints limiting their production. During the analysis, each farmer's first, second and third priority was given the score of 4, 3, 2 and 1 respectively, then worked out as average score per

Table 4 Farmer's declared priorities and observed crop production constraints

	Sahel Savanna	Sudan Savanna	Guinea Savanna
1. Farmer's declared priority*			
– To ensure that there is enough food for the family throughout the year.	3.4	3.8	3.6
– To earn sufficient money for the vital basic needs of the farmer's family	1.2	2.9	2.6
2. Farmers's preferred major food crops*			
Maize	2.3	3.7	3.4
Sorghum	5.8	4.4	4.1
Millets	4.6	1.8	1.6
Yams	–	5.8	5.0
Beans/Cowpeas	1.0	1.5	1.0
3. Farmer observed constraints (percentage of farmers)			
– late rains	61	–	41
– problem of striga weeds	–	57	–
– poor soils	–	28	–
– torential showers causing water logging or erosion	54	–	70

* Scores for farmer's priorities are worked out of 4 and for preferred food crops, worked out of 6.

Table 5 Factors causing 10-15% losses of crop yields on farmer's fields in 1984 and 1985

Factor	Crops	Percentage of Farmers		
		Sahel Savanna	Sudan Savanna	Northern Guinea Savanna
Late rains	Maize	–	42	51
	Millets	15	–	10
	Sorghum	7	57	45
	Yams		42	53
	Cotton			22
Poor soils	Sorghum	7	90	46
	Yams		64	59
Moisture stress	Millets	15		12
	Maize			51
	Sorghum	71	28	22
	Cotton	14		22

farmer per type of priority. For proferred food crops each farmer's first, second, . . . 6th choice was given scores of 6, 5, 4, 3, 2, and 1 respectively, then worked out an average per choice per farmer.

Table 4 shows farmer's scores of their priorities and production constraints. Taking farming as an occupation, farmers declared two priorities that they tried to achieve. The priority for farmers was to ensure that there is enough food for the family throughout the year. This priority had a rank score of 3.4, 3.8 and 3.6 in Sahelian, Sudan and Guinea savanna zones respectively. The second priority given by farmers was to earn sufficient money for the family's vital basic needs. Sorghum and millets are preferred food crops for farmers in the Sahelian savanna zone, while yams, sorghum and maize were preferred food crops for farmers in both Sudan and Northern Guinea savanna zones.

In the Sahelian savanna late rains and torential showers causing water logging were the farmers observed production constraints. In the Sudan savanna farmers gave the problems as *Striga* weed, and poor soils as their main production constraints.

In the Northern Guinea savanna, farmers considered late rains and torrential showers causing erosion as factors limiting crop production. Late rains and poor soils, followed by moisture stress, emerged as major crop production constraints causing 10 to 15% losses of crop yields in 1984 and 1985. Late rains affected maize, millets, yams, sorghum and cotton in various degrees in each agroclimatic zone (see Table 5). Poor soils mostly affected sorghum and yams in both the Sudan and Northern Guinea savanna zones. While moisture stress affected mostly millets, sorghum and cotton in both the Sahelian and Northern Guinea savanna zones. It also affected maize in the Northern Guinea savanna.

Table 6 Mechanical and Chemical composition of Soils at selected sites.

Site	Bensekou B	Ina C	Birni Lafia A	Boukoumbè B	Ouake C	Guilmaro C
Size % (2mm) very coarse	0.60	2.70	1.50	0.60	1.30	1.10
0-2 μ % coarse sand	6.32	9.4	17.44	9.64	8.40	10.02
0-20 μ % fine sand	4.80	12.75	10.77	13.80	6.18	3.76
20-50 μ % silt	8.49	15.18	25.61	29.69	19.69	5.01
50-200 μ % clay	49.74	38.03	26.52	23.87	41.77	37.11
200-200 μ % fine clay	31.14	23.63	18.87	23.40	22.94	45.46
Org. C. (%)	0.75	0.77	1.49	0.59	0.83	0.61
Total-N (%)	0.070	0.067	0.129	0.049	0.062	0.056
C/N ratio	10.7	11.5	11.5	10.8	13.4	10.9
O.M. (%)	1.29	1.33	2.57	0.91	1.43	1.05
pH in water 1 × 2.5	7.0	6.8	6.7	6.0	6.0	5.9
pH KCL 1:2.5	6.2	6.0	5.8	5.3	5.5	5.0
Exchangeable cations						
Ca ++ meq/100g	3.40	4.40	4.75	4.55	2.80	2.20
Mg + meq/100g	1.55	1.60	2.75	1.20	0.80	1.30
K + meq/100g	0.32	0.39	0.50	0.44	0.23	0.18
Na + meq/100g	0.56	0.52	0.54	0.60	0.49	0.53
Total cations meq/100g	5.83	6.91	8.54	6.79	4.32	4.21
CEC meq/100g	6.90	7.70	9.50	9.60	5.35	7.10
% base saturation	84	88	90	71	81	59
Avail. P (Bray – 1) ppm	8	15	4	6	4	3
Rain fall	760.5	1170	412.4	800	1100	1050

(a) Sahel (b) Sudan (c) Northern Guinea

Mechanical and Chemical composition of soils

As seen in Tables 4 and 5, 50 to 60 percent of the farmers in Sudan and Northern Guinea savanna ranked poor soils as one of the most limiting crop production constraints. Mechanical and chemical composition of soils at sites selected from the three agroclimatic zones are presented in Table 6. The chemical composition analysis suggested that soils in the area, are sandyclay, with low organic matter content, very low in total nitrogen and exchangeable cations.

Integrated Approaches being studied for improving Agricultural Production in Northern Benin

On the basis of the existing production systems in northern Benin, some approaches to improve the production system are being studied in order to (i) introduce appropriate agronomic and technical interventions, incorporating crop and livestock production systems including trees so as to recycle manure, organic matter and other soil nutrients. (ii) conserve soil water resource, in order to reduce the problem of drought and related production constraints with reference to farmer's socioeconomic conditions. The approaches are now discussed below:

Agronomic and technical studies

In view of the findings from the socioeconomic surveys carried out in Northern Benin (SAFGRAD/FSR/Benin, 1985) studies of some production technologies, namely use of fertilization especially on food crops, ridging as compared to planting on flat, crop association of maize/sorghum, maize/groundnuts, sorghum/cowpeas and cotton/maize or cotton/cowpeas planted on ridges or flat with or without fertilization have been initiated.

From the socioeconomic studies it was shown that farmers in Northern Benin recognise interplanting two or three crops has four economic advantages; (a) it ensures maximum production (by providing variety of sources) for satisfying minimum calorie requirements of the family and farm cash income (c) reduces risks of crop failure in cases of moisture stress caused by dry spells or erratic rainfall and (d) it increases the quantity of crop residues for various purposes. However, some farmers in that region who, due to lack of appropriate agronomic techniques interplant repeatedly cereal crops like maize/sorghum or sorghum/millets have observed that this practice cause soil fertility to degenerate much faster especially since they do not use chemical fertilizers on food crops.

Although there is a significant interaction between crop variety and fertilization when crops are planted in pure stand, observations so far suggest that crop association of maize/sorghum without fertilization is not necessarily significantly different from that with fertilization.

In the Sudan Savanna where the soils are more sandy-clay and very low in fertility, there tends to be greater response to chemical fertilizers. However there is a general trend suggesting that mixed cropping allows for better utilization of farm resources under low fertility levels. There are also indications that in both Sahel and Sudan savanna zones local maize and sorghum varieties are highly stable under farmer conditions.

Labour saving techniques

As indicated earlier, one of the major constraints in the production systems of the semi-arid area is the amount of labour required to complete the farming operations in a very limited time. Because of the unique conditions in this area where soils are hardened and difficult to dig before the rains, and the need to complete planting soon after the on-set of rains, the period of tilling the soil and planting is extremely very critical. There are strong indications that the use of ox-pough for soil preparation may have significant results on total production. The use of small planting tools like "roullete" and grain seeder is also being incorporated. The other labour saving techniques being considered are use of ridger, ridge-tyer, herbicides particularly in cotton, use of groundnut sheller and encouraging setting up of tractor hiring services.

Crop-Tree and Livestock Interaction

Since the semi-arid areas besides being deprived of few trees and scanty vegetation, also support a large stock of animals, the need for increasing crop–tree and livestock interaction is crucial.

Some of the ways for achieving this, are (i) to interplant leguminous shrubs like sun hemp (*Crotolaria* sp) with crops, (ii) interplant at wide spacings, some selected tree species with crops and (iii) encouraging farmers to plant wood lots on their farms. If the Sun hemp is well adapted to the local conditions, it can serve as a source of green manure for crops and a source of animal feed thus enhancing the supporting capacity of the land for both crops and livestock. This can also increase the chances of returning animal droppings to the land being used for crop production.

Moreover, since farmers are becoming increasingly interested in oxen for draught power, the need for them to have a source of animal feed on their own farms becomes imperative. Furthermore, incorporation of trees in the production system can increase soil nutrient recycling and check desert encroachment.

Soil–Water Conservation

Appropriate soil–water conservation techniques are urgently needed to prevent total crop failures under drought conditions. There are indications that tied-ridges can prolong the water-holding capacity of the field after a good rainfall (FSU Annual Report 1983, 1984). Another soil-water conservation technique for such zone, is bunding larger surfaces of the farm to make rain-water stay longer on the field. Water catchment techniques like construction of earth dams or trenches near cropped fields can trap rain water use as supplementary irrigation if the rains cut off prematurely.

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45 Quelques mecanismes d'adjustement des systèmes de production agricole au Burkina Faso implications pour la recherche et le developpement agricole

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Introduction

Depuis la sécheresse du début des années 1970 en Afrique, des éfforts considérables ont été déployés dans les domaines de la recherche et du développement pour éviter que les graves conséquences de la sécheresse ne se reproduisent. Les projets de recherche et de développement en Afrique au sud du Sahara depuis cette époque font partie de ces efforts. Toutefois, peu d'éfforts ont pris en compte les initiatives ou les tentatives faites par les populations concernées pour essayer de resoudre elles-mêmes leurs problèmes; et ceci peut constituer l'une des principales raisons pour lesquelles plusieurs éfforts destinés à aider les petits paysans de la region ont échoué ou ont eu très peu de succès.

Outre le problème de la sécheresse, les paysans de la région semi aride du Burkina Faso ont eu à faire face ces dernières années à un autre problème causé par la pression démographique croissante et l'integration croissante de leurs système de production dans l'economie de marché. Il s'agit du problème de terre caractérisé par une pénurie croissante de bonnes terres arables auquel s'associe la dégradation de la fertilité des sols. Le premier provenant d'une augmentation de la demande en terres et le second provenant d'un accroissement conséquent de l'intensité d'utilisation des terres.

Le but de cette communication est de faire les deux observations suivantes et de les soutenir avec des faits observés au Burkina Faso.

1. Les systemes de production agricole paysannes sont des systèmes dynamiques possédant des mecanismes d'ajustement qui leur permettent de s'adapter aux changements dans leurs conditions environnementales de facon a minimizer ou eliminer les effets négatifs de ces changements sur leur objectifs de production.
2. La connaissance des mécanismes d'ajustement d'un système de production donné peut être trés utile au développement de technologies et d'actions de développement appropriées pour satisfaire éfficacement les besoins technologiques et autres des petits paysans.

Les systèmes de production agricole au Burkina Faso

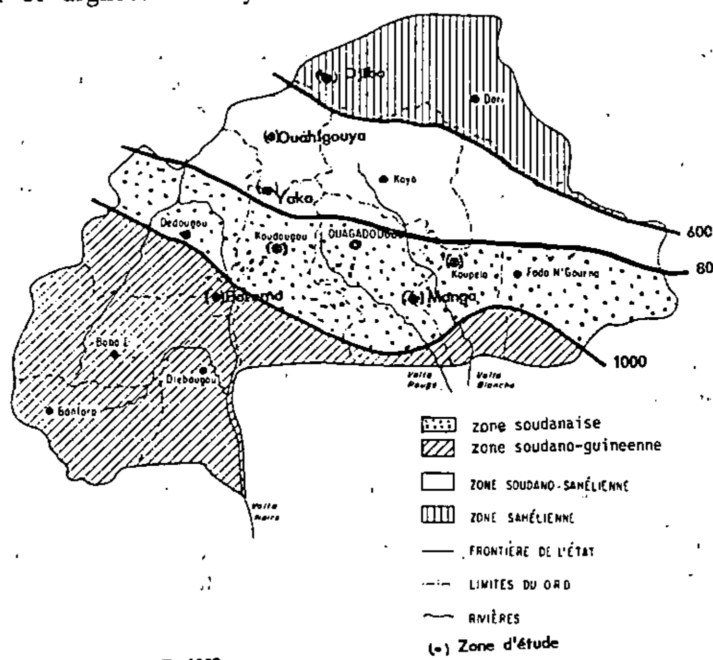
Le Burkina Faso s'étend sur quatre zones agroclimatiques qui sont du sud au nord:

- La zone de savanne soudano guineenne avec une pluviometrie à long terme entre 1000 et 1400 mm par an.
- La zone de savanne soudanienne avec une pluviometrie à long terme entre 800 et 1000 mm par an.
- La zone soudano sahelienne avec une pluviometrie à long terme de l'ordre de 600 á 800 mm par an.
- La zone sahelienne avec une pluviometrie à long terme entre 400 et 600 mm par an.

Comme indiqué sur la Figure 1, la moyenne pluviometrique à long terme baisse du sud vers le nord du pays. Quant à l'instabilité de la pluviometrie, elle croit du sud vers le nord.

Les faits mentionnés dans cette communication ont été observés dans toutes les quatres zones agroclimatiques, dans des villages au nombre de deux à cinq situés dans sept localités différentes du pays. Ces faits ont été observés au cours d'enquêtes de reconnaissance et d'enquêtes de base menées entre Mars 1981 et Mars 1986 dans ces villages. Il s'agit d'enquêtes de base dans des villages-laboratoires de l'ICRISAT situés dans les régions de Djibo, Yako et Boromo, au nombre de deux villages par site, et d'enquêtes de base conduites dans deux villages de la région de Manga. Les résultats de récentes enquêtes de reconnaissance conduites en Février 1986 dans quatre villages dans la région de Ouahigouya, cinq villages dans la région de Koudougou, et cinq villages dans la région de Koupéla font également partie des données exploitées.

Le système de culture dans la zone sahélienne est surtout caracterisé par une culture extensive de petit mil associé au niébé sur les sols de plateau profonds et sablonneux, et par la culture du sorgho dans quelques basfonds limoneux et argileux. Le système de culture dans les zones soudano



Source : GERDAT, 1983.
Adaptation

Figure 1 Zones agroclimatiques au Burkina Faso sahélienne et soudanienne est caractérisé principalement par une culture de mil et de sorgho sur les sols de plateau et par la culture du sorgho dans les basfonds. Dans la zone soudano guinéenne le système de culture est surtout caractérisé par la culture du sorgho, du mil, du coton et du riz sur des sols de plateau et dans des basfonds. En general l'importance relative du petit mil dans les systemes de culture décroit du nord vers le sud, pendant que celle du sorgho croit dans le même sens.

En ce qui concerne la production animale, la plupart des paysans élévent de la volaille et des petits ruminants un peu partout dans le pays, à cela s'ajoute l'élevage de porcs dans la zone nord guinéenne. L'élevage debovins est surtout l'affaire des tribus Fulani ou Peuhl. Le système d'élevage desbovins est surtout un systeme de transhumance dans le sahel où quelques paysans possèdent des bovins et intègrent leur elevage aux activités de culture. Ailleurs, peu de paysans possèdent et maintiennent des bovins sur leurs exploitations agricoles. Les paysans dans les autres zones ont tendance a confier leurs bovins aux Peuhl qui les élèvent de manière plus ou moins sédentaire autour des villages, ou pratiquent la transhumance vers le sud en saison sèche. Une relation symbiotique se développe généralement entre cultivateurs et éleveurs permettant des échanges de résidus de culture contre du fumier bovin obtenu grace à des parcages de bovins sur les champs des paysans.

Les populations rurales du Burkina Faso ont souffert au cours de la dernière décenie d'une baisse substantielle de la pluviométrie et d'une distribution de plus en plus hasardeuse de la pluviométrie. La pluviométrie annuelle dans les sept localités ayant fait l'objet d'études a baissé par exemple entre les années 1956-65 et 1971-80 comme indiqué au Tableau 1.

La pression démographique dans le pays a atteint son plus haut niveau sur le plateau Mossi où se situent cinq des sept localités etudiées (Ouahigouya, Yako, Koudougou, Koupéla, Manga). Il s'agit des localités situées dans la zone soudanienne et soudano sahelienne. La pression démographique sur la terre arable utile avait été avaluée à la fin de la dernière decenie à 107 habitants/km^2 sur le Plateau Mossi, 36 habitants/km^2 dans le sahel, 37 habitants/km^2 dans la zone nord guinéenne et 26 habitants/km^2 à l'est du pays (Reij., 1983). La pression démographique continue de croitre à environ 2% per an.

Les paysans de la region, (particulièrement ceux du Plateau Mossi) ont eu à faire face au cours des dernières années à deux principaux problèmes: Le problème de la sécheresse et le problème de la pénurie grandissante de

Tableau 1 Changement de la pluviometrie entre 1956-65 et 1971-80 dans les zones d'etudes.

Localité	Pluviométrie Annuelle Moyenne (mm) 1956-65	Pluviométrie Annuelle Moyenne (mm) 1971-80	Pourcentage de déclin (%)
Djibo	640	410	36
Ouahigouya	715	568	21
Yako	787	684	13
Koudougou	897	658	27
Koupéla	883	773	12
Manga	940	856	9
Boromo	910	858	6

bonnes terres arables. Le problème de sécheresse croit du sud vers le nord tandisque le problème de terre est plus crucial sur le Plateau Mossi qu'a l'extérieur du plateau. Les ajustements (ou adaptations) observés dans les villages étudiés sont destinés à resoudre les deux problèmes ensemble, mais beaucoup plus pour resoudre le probleme de la sécheresse au fur et à mesure qu'on avance vers le nord, surtout en dehors du Plateau Mossi, et beaucoup plus pour resoudre le problème de terre quand on descend vers le sud et particulièrement sur le Plateau Mossi.

Les mecanismes d'ajustement

Les mecanismes d'ajustement observés ont deux principales composantes qui sont:

- Changements ou innovations technologiques
- Reaffectation de resources.

On observe aussi quelques changements institutionnels. En général les mécanismes d'ajustement observés dans l'ensemble des villages etudiés peuvent se résumer come suit:

1. Changements ou innovations technologiques
   a. Recherche, test et adoption de variétés précoces de cultures vivrières (surtout les céréales) importées à partir d'autres villages ou zones agroclimatiques.
   b. Extention de l'utilisation des techniques traditionnelles d'économie de l'eau et de conservation du sol en dehors des endroits où ils sont traditionnellement utilisés. A ceci s'ajoute également la construction d'un nombre de plus en plus croissant de retenues d'eau et de petits barrages avec des techniques traditionnelles.
   c. Intensification de l'agriculture à travers un plus grand usage de fumures organiques et d'outils attellés.
   d. Une plus large adoption de pratiques culturales à haut risques destinés à gagner du temps dans l'accomplissement des activites culturales de la saison.
2. Reaffectation des Resources
   a. Une plus grande exploitation des zones de basfonds.
   b. Des substitutions de cultures qui conduisent à des changements parfois radicaux dans le système de culture.
   c. Une réduction progressive des superficies plantées en cultures de rente non consommables tel que le coton.
   d. Accroissement des investissements dans l'élevage et dans les activités extra agricoles (commerce).
   e. Une accentuation de l'intégration entre l'agriculture et l'élevage.
   f. L'émigration.
   g. La mise en culture des terres marginales distantes et/ou peu fertiles.

Le principal changement institutionnel le plus souvent remarqué est une individualisation croissante du regime foncier du mode collectif d'usufruit au mode individuel de proprieté privée en passant par un mode de propriété familiale (Matlon et Vierich, 1982).

Changements et Innovations Technologiques

Changements varietaux

Il apparait clairement dans la presque totalité des villages visités que les paysans sont constamment entrain de rechecher et d'experimenter de nouvelles variétés (ou ecotypes) de cultures vivriéres importées à partir de villages lointains ou voisins et à partir d'autres zones agroclimatiques pour satisfaire leurs besoins varietaux. La même observation a été faite dans les villages laboratoires de l'ICRISAT au Burkina Faso par Vierich qui conclut qu'il n'existe pas de variétés locales auxquelles les paysans tiennent pour des raisons sentimentales (Matlon et Vierich, 1982, p.G. 82).

La remarque qui s'impose est qu'il existe dans beaucoup de cas des processus indigènes de sélection de cultures dont l'objectif principal est de satisfaire les objectifs specifiques et constament variables des paysans. Ces processus indigènes et leur critères de selection sont pratiquement ignorés et ne sont pas pris en compte par la plupart des sélectionneurs dans leurs programmes de recherches. Un tel fait constitue une lacune qui empêche la définition de critères de sélection appropriés dans la plupart des programmes de recherche.

Au cours des dernières années, le processus indigène de sélection de cultures a comme la plupart des programmes de sélection en station de la region, mis un accent particulier sur la collecte et le test de variétés de mil, de sorgho, de maïs et de niébé qui échappent à la sécheresse ou qui tolèrent la sécheresse. Toutefois, le materiel utilisé, la méthode utilisée et les objectifs poursuivis diffèrent de part et d'autre. Un tel parallelisme dans la selection de cultures, accroit le risque de produire en station des variétés totalement inadaptées aux conditions réelles des systèmes de production et aux besoins varietaux des paysans. Un tel risque peut être réduit en tenant compte des critères, materiaux et méthodes des processus indigènes de sélection lors du développement des programmes de sélection en station.

Les données collectées dans les villages étudiés montrent que le processus indigène de sélection a consisté au cours de ces dernières années à importer des variétés plus précoces de zones agroclimatiques plus sèches du Burkina Faso, du Mali et dú Niger, aussi bien que de la zone nord guinéenne du Togo, Benin et Ghana. Les variétés importées portent d'habitude les noms de leurs lieux d'origine et sont souvent apportées dans le village par des émigrants et des éleveurs Peuhl pendant la transhumance. Les nouvelles variétés portent aussi parfois les noms des personnes qui les ont plantées les premières dans le village, si bien que leur origine est généralement facile à retrouver.

Bien que l'accent soit mis sur les variétés précoces, le processus indigène de sélection n'ignore pas pour autant les variétés à long cycle. Ces variétés (ou écotypes) sont déplacées vers les zones de basfond pour y être plantées sur des sols disposant de meilleures capacités de retention en eau. Les resultats de nos récentes enquêtes de reconnaissances montrent que le nombre de variétés de chaque cutlure vivrière dans chaque village visité varie entre deux et cinq avec des cycles differents. Le cycle pour les variétés de petit mil varie par exemple entre 70 et 100 jours dans la zone soudano sahélienne, entre 90 et 180 jours dans la zone soudanienne (INERA-RSP, 1986).

D'après des enquêtes de base conduites dans trois villages de l'ICRISAT en 1982, Vierich (Matlon et Vierich, 1982) a également rapporté l'existence dans les villages etudiés de systèmes d'experimentation paysanne, parfois sophistiqués avec des variétés importées. Elle trouva par exemple que les paysans du village de Ouré (vers Djibo) dans la zone sahélienne plantaient en 1982 au moins sept variétés de petit mil, testaient et adoptaient de plus en plus une nouvelle variété nommée "Hairi" importée du Mali depuis dix ans. Cette variété ayant sur l'ancienne variété la plus populaire nommée "Djelgadjil" l'avantage d'être plus précoce et d'avoir des épis qui perdent moins facilement leurs grains de telle facon que les pertes pendant les récoltes sont réduites. La nouvelle variété serait surtout adoptée par les paysans qui veulent aussi une récolte précoce même si les rendements sont bas.

Vierich a également observé de pareils modes d'expérimentation paysanne et d'adoption à Kolbila (près de Yako) dans la zone soudano sahelienne et à Koho (près de Boromo) dans la zone nord guinéenne. Ainsi en 1982, les paysans de Kolbila cultivaient au moins onze varietes (ou écotypes) de sorgho blanc et 15 des 24 paysans interviewés avaient eu à changer leurs variétés de sorgho au cours des quinze dernières années. A Koho, une variété ameliorée de sorgho blanc introduite dans le village depuis dix ans par les services d'encadrement est entrain de perdre du terrain face à une variété récemment introduite par les pasteurs Fulani (Peuhl).

En resume, les paysans sont entrain d'adopter de plus en pus des variétés précoces importées qui ont de meilleures performances dans les conditions agroclimatiques et édaphiques actuelles en terme de precocité, de résistance à la sécheresse et de rendement. Le nombre et les types de variétés utilisées par un paysan donné dépendent surtout des types de sol auquel il a accès et de ses objectifs de production.

Les resultats des enquètes menées suggèrent que le processus indigène de sélection est purement empirique, n'a aucune composante physiologique et ne comporte pas des manipulations génétiques (croisements). La différence principale entre le processus indigène de sélection et le processus de sélection en station se situe au niveau des objectifs poursuivis et par conséquent au niveau des critères de sélection. Pour resoudre le problème de la sécheresse par exemple, les programmes de sélection en station ont tendance à rechercher et à recommander pour une zone agroécologique donnée, une ou deux variétés qui échappent à la sécheresse ou tolérent la sécheresse, et qui ont les meilleures performances en terme de rendement. Le paysan de l'autre côté tend à rechercher et à adopter des variétés qui lui permettent de satisfaire au mieux ses objectifs de production dans les nouvelles conditions de sécheresse et qui sont adaptées ou facilement adaptables à ses pratiques culturales et à ses pratiques de conservation et stockage des produits de la récolte.

La pluviométrie et le type de sol sont les principales conditions environnementales prises en compte par les deux processus de sélection. Toutefois, en sélectionnant pour une zone agro écologique donnée les programmes de sélection en station ont tendance à supposer une homogeinité du type de sol régional et à sélectionner des variétés qui ont les meilleures performances sur ce sol avec ou sans une dose donnée d'engrais. Les paysans par contre font la selection pour chacun des types de sols locaux (representant differentes capacités de retention d'eau au champ et de fertilité) qui se trouvent dans leur environnement et pour chacun des trois types de champs que sont les champs de case, les champs de village et les champs de brousse, qui en fait representent en général differents niveaux de fertilité du sol. Ainsi, le long d'une toposéquence par example, la tendance chez les paysans est de retenir les variétés les plus précoces ou les plus tolérantes à la sécheresse pour les sols de plateau disposant de faibles capacites de retention en eau, de retenir les variétés à cycles intermediaires pour les sols á mi-pente disposant de capacités médianes de retention en eau et de retenir les variétés à cycles plus long pour les sols de basfonds disposant de capacités de retention en eau relativement plus elevées.

L'évaluation d'une variété nouvellement introduite se fait en fonction des differents objectifs de production du paysan et non pas seulement en fonction du rendement. Ainsi les variétés les plus précoces peuvent être retenues pour la periode de soudure même si leurs rendements sont relativement bas comparativement aux rendements d'autres variétés résistantes à la sécheresse, alors que des variétés plus productives et à cycles plus longs peuvent être retenus à des fins de stockage et de vente. Dans ce dernier cas par exemple, la capacite des grains de chaque variété à bien se comporter dans les conditions de conservation et de stockage du paysan constitue un critère de selection fondamental. En fin de compte, le paysan recherche et adopte une gamme de variétés qui remplissent des conditions et des fonctions differentes au sein du système de production agricole.

L'implication majeure de cet exemple de processus de selection indigène est que les sélectionneurs en station devraient systematiquement considérer la capacité de retention en eau utile du sol et le niveau de fertilité du sol comme variables experimentales dans leurs programmes de selection. Ils devraient aussi tenir compte des objectifs multiples des paysans afin de leur proposer des variétés capables d'avoir un rendement minimun "raisonnable" dans les conditions environnementales réelles du paysan et capables de remplir l'une ou l'autre des fonctions assignées à la culture dans le système de production.

Extension de l'utilisation des techniques traditionnelles d'économie de l'eau et de conservation du sol

La généralisation de plus en plus remarquable de l'utilisation des techniques traditionnelles d'économie de l'eau et de conservation du sol dans les champs, réflète les efforts deployés par les paysans pour resoudre le problème de dégradation de la fertilité des sols par érosion et compaction et le problème d'insuffisance d'eau dans le sol dû à la sécheresse. Le phénomène a été observé dans tous les villages étudiés, et particulièrement ceux situés sur le Plateau Mossi où la pression démographique est la plus forte. Il consiste a étendre à d'autres champs l'usage des techniques de conservation d'eau et de sol (CES) que l'on trouve habituellement dans les champs portant des cultures hautement valorisées par le paysan (ex.: maïs, tabac) et dans les champs les plus supseptibles à l'érosion par les eaux de ruissellement. Les principales techniques traditionnelles de conservation d'eau et de sol sont les cordons de pierres, l'enherbement (surtout avec Andropogon Gayanus) et le paillage. Les cordons de pierres et les lignes d'herbes disposés à travers champs et perpendiculairement à la pente permettent aux paysans de réduire la vitesse de ruissellement des eaux de pluie et d'accroitre leur infiltration dans le sol tout en reduisant ainsi leurs effets erosifs. Le paillage est surtout effectué dans les endroits du champ où le sol devient fortement compact (une autre conséquence de la sécheresse) de manière à encourager l'activité microbienne des termites, à réduire l'évaporation et accroitre l'humidité et la fertilité physique du sol en général.

La conservation de l'eau et du sol a été également au centre des préoccupations d'un certain nombre de projets de recherche et de développement dans la region au cours de ces dernières années.

Malheureusement peu d'attention ont été prêtées au depart aux techniques traditionnelles dans ce domaine. La plupart des éfforts de recherche ont été concentrés sur le travail du sol et les billons cloisonnés tandisque la majeure partie des resources de développement dans le domaine a été consacrée à la construction de diguettes en terre. La technique de billons cloisonnés se trouve confronté à une sérieuse contrainte de main d'oeuvre qui doit être allégée avant qu'on ne puisse s'attendre à une adoption à grande échelle de cette technique. Par ailleurs, les diguettes en terre ont été construites un peu partout dans beaucoup de villages grâce aux actions du FEER (Fonds de l'Eau et de l'Equipement Rural), un organisme étatique qui intervient pour le financement des equipements ruraux avec des fonds provenant de la Banque Mondiale et d'autres partenaires financiers.

Bien qu'ils apprécient la construction des diguettes dans leurs champs et villages, la plupart des paysans ont de facon consistente estimé au cours d'interviews que leur système de collecte d'eau avec des cordons de pierres est meilleure au systeme anti-erosif que constituent les diguettes en terre pour differentes raisons techniques et economiques (Thiombiano, 1985). OXFAM (Oxford Famine Relief Organisation) est une des rares institutions de recherche-developpement qui ont etudié les systèmes CES traditionnels en vue de leur amélioration au Burkina Faso (Wright, 1983; 1985). De récents tests d'évaluation conduit dans plus de vingt cinq villages, dans des champs de paysans pour comparer la technique de cordons de pierres à celle des diguettes en terre ont confirmé la supériorité de la technique de cordon de pierres sur celle des diguettes en terre[1]. Suite à de telles remarques, plusieurs institutions de développement se sont recemment interessés à la promotion de la technique de cordons de pierres sous diverses formes ameliorées en milieu paysan.

Cet exemple démontre que l'identification et l'amélioration des solutions techniques que les paysans eux mêmes apportent à leurs problèmes peut constituer un processus très efficace de développement de technologies. De telles alternatives ne devraient pas être ignorées par les éfforts de recherche et de développement destinés à aider les petits paysans. En fait, de telles alternatives devraient être systématiquement considérées avant toute tentative de transfert ou de création de nouvelles solutions.*

Intensification de l'agriculture par accroisement de l'usage de la fumure organique et des outils attellés

Face à la persistance de la sécheresse, les paysans au Burkina Faso ont tendance à compter beaucoup plus sur la fumure organique et à diminuer l'utilisation des fumures minérales. Ainsi dans certains villages, l'usage des engrais chimiques a pratiquement disparu ces dernières années à cause du risque financier plus élevé associé à l'application des engrais en conditions de sécheresse (INERA-RSP, 1986). Là où la sécheresse constitue un problème majeur, les paysans ont tendance également à acquérir et à utliser des outils attéllés pour ameublir les sols compacts pour accroitre l'infiltration

[1] Communications personnelles de resultats de tests conduits par le FEER en collaboration avec l'ICRISAT. Resultats non encore publiés.

* Les paysans dans la plupart des villages entreprennent également des actions collectives de construction de puits et de retenues d'eau pour accroitre la disponibilité en eau au cours de l'année pour la consommation humaine et animale. La recherche et le developpement agricole ont jusqu'a present accordé peu d'attention a ces initiatives qui meritent beaucoup plus d'attention.

de l'eau. Ces outils sont également obtenus pour faciliter l'exploitation des zones de basfonds vers lesquels plusieurs champs sont déplacés et où l'utilisation des fumures minérales tend plus ou moins à se limiter.

Là où la pression démographique apparait comme le principal problème, l'usage des fumures organiques devient de plus en plus important mais avec un maintient de l'usage d'engrais chimiques. Ces derniers sont surtout utilisés dans les champs lointains ou sur champs situés sur des sols peu fertiles. Ceci se verifie surtout au sud du pays (par example à Manga) où le risque de sécheresse est moins élevé. Dans ce cas, les outils attellés sont également obtenus pour étendre les superficies cultivées aux terres marginales, lointaines et vierges.

Les paysans ont tendance non seulement à accroitre leur production de fumures organiques mais également à les appliquer de manière beaucoup plus éfficace (par exemple en appliquant la fumure dans les poquets lorsqu'il y a suffisament de main d'oeuvre). Des efforts de développement sont présentement en cours au Burkina Faso pour promouvoir l'usage des fosses fumières par les paysans, mais peu de recherches adaptives ont été conduites sur le sujet dans le pays. Des efforts de recherche et de développement sont nécessaires dans ce contexte pour ameliorer les techniques de production des fumures organiques, pour vulgariser les techniques et reduire les coûts de transport du fumier au champ. Le probleme de transport du fumier constitue le facteur le plus limitant pour une application efficiente du peu de fumier disponible dans les champs au Burkina Faso (Prudencio, 1983).

Large adoption des pratiques culturales a haut risque destinées à gagner du temps

Le semis à sec au mois d'Avril ou de Mai, avant l'installation des pluies est une stratégie employée par certains paysans au Burkina Faso pour gagner du temps et semer le plus de superficies possibles avant la fin des premières pluies. Il est apparu à travers les récentes enquêtes de reconnaissance que cete pratique est de plus en plus adoptée par un nombre grandissant de paysans au fur et à mesure que la pluviometrie devient de plus en plus aléatoire, malgré le risque plus élevé que cela implique. La plupart des paysans estiment que la pratique reussit dans 50% des cas et ont mis au point des moyens pour l'améliorer (usage d'insecticides, de fumier dans les poquets, etc. de façon à accroitre les chances de succes. Apparemment aucun programme de recherche dans le pays ne s'est systématiquement penché sur cette pratique culturale pour l'examiner de plus près.

Reaffectation de Resources

Le mode précis de réaffectation des resources provoqué par un changement dans les conditions environnementales varie d'un système de production à un autre en fonction des resources disponibles et en fonction des conditions environnementales specifiques du système. Toutefois les éléments communs qui caractérisent le plus souvent les processus de réaffectation de resources observés au Burkina Faso sont ceux précédemment cités au debut de la section 3. A cause de la nature généralement complexe du processus de réaffectation des resources, nous nous limiterons dans la suite de cette communication à une seule étude de cas au Burkina Faso.

Une étude approfondie du système de production agricole de Nonghin, un village situé dans la region de Manga (Prudencio, 1983) a révélé plusieurs caractéristiques et mécanismes d'ajustement des systèmes de production agricole soudaniens confrontés aux problèmes de terre et de sécheresse.

Les caracteristiques du systeme de culture à Nonghin

Le système de culture à Nonghin est un système de culture en anneaux comportant au maximum cinq anneaux de culture qui sont en fait differents anneaux de gestion de la fertilité du sol et des cultures. En tracant des cercles concentriques autour de la concession d'un ménage donné dans le village, on se rend aisément compte que tous les champs situés à une certaine distance de la concession (dans un anneau) sont semblables en termes de séquence ou rotation de cultures, d'association de cultures, d'application de fumures et de techniques de conservation du sol. Sur la base de ces critères on distingue au maximum cinq anneaux de gestion sol-cultures dans le village pour chaque ménage. Toutefois, trois de ces cinq anneaux sont présents dans chaque cas, les deux autres anneaux étant des anneaux à caractères intermédiaires. Le systeme de cultures simplifié avec les trois principaux anneaux se presente schématiquement comme sur la Figure 2:

Les champsa du premier anneau portent continuellement des cultures de maïs et des plantes à sauce ou du mais en rotation avec du sorgho rouge. Ces champs recoivent chaque année de fortes doses de fumures organiques (en moyenne 9 tonnes/ha) et portent en général des dispositifs de conservation de l'eau et du sol tel que des cordons de pierres en bordure des champs pour arrêter l'eau et réduire l'érosion (sur 94% des champs). Ces champs sont les champs les plus proches des concesions, par conséquent la plupart sont des champs de case et leur superficie se situe autour de 0,05 hectare.

Les champs du deuxième anneau portent continuellement des cultures de sorgho rouge associé au niébé, ces champs recoivent des doses modérées de fumures organiques (1, 3 tonne/ha) et de la fumure minerale (25 kg/ha d'engrais coton sur 45% des superficies cultivées par an), mais avec la présence de très peu de dispositifs de conservation de l'eau et du sol. La plupart des champs du deuxième anneau sont des champs de village et ont une superficie d'environ 0,3 hectare.

Le troisième anneau est caractérisé par une culture extensive de petit mil associé à du sorgho blanc et à du niébé. La fertilité du sol y est restorée avec

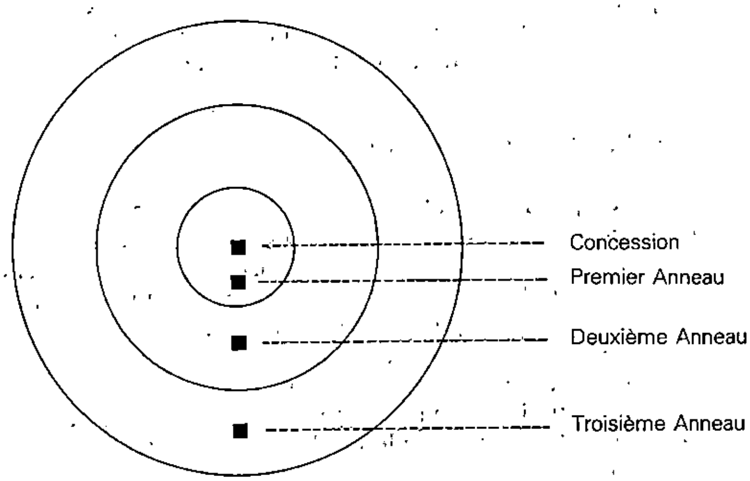


Figure 2 Le système de culture en anneaux de Nonghin simplifié.

des jachères (dont la durée moyenne a considerablement diminué au cours des deux dernières décenies de 20 ans à 3 ans et de la fumure minérale (en moyenne 20 kg/ha d'engrais coton sur 26% des superfices cultivees annuellement) et avec quelques dispositifs de conservation de l'eau et du sol (sur 12% des champs). La plupart des champs du troisième anneau sont des champs de brousse et ont une superficie d'environ 0,9 hectare.

Reaffectation des resources dans le système de cutlure de Nonghin

Une analyse de l'histroie des champs et une analyse transversale comparant les pratiques culturales des paysans ayant accès à une quantité limitée de terres à celles de paysans ayant accès a des quantités relativement elevées de terre à révéllé ce qui suit: Au fur et à mesure que la pression sur les terres et l'intensité d'utilisation des terres augmentent, on observe un élargissement du deuxième anneau de culture et un rétréssissement du troisième anneau. En d'autres termes, le sorgho rouge est progressivement substitué au petit mil et au sorgho blanc, il y a accroissement dans l'utilisation des fumures organiques et minérales et une disparution progressive de la jachère.

Ce type d'ajustement est principalement une réaction face à l'indisponibilité croissante de terres. La substitution du sorgho rouge à la place du petit mil et du sorgho blanc constitue l'élément central du mécanisme d'ajustement à cause des avantages suivants que les variétés locales de sorgho rouge auraient sur les variétés locales de mil et de sorgho blanc à Nonghin. Ces avantages, selon la perception des paysans sont les suivants:

- Là où le sorgho et le mil sont cultivés dans des conditions semblables, le rendement en grains des variétés locales de sorgho rouge est superieur au rendements en grains des variétés locales de petit mil et de sorgho blanc. Par conséquent la capacité du sorgho rouge à permettre au paysan d'atteindre son objectif de securité alimentaire est plus élevé que celle du petit mil et du sorgho blanc, bien que sur le plan alimentaire le sorgho rouge soit la céréale la moins préféree.*
- Le sorgho rouge a d'apres les paysans la réputation de mieux répondre aux fumures organiques et minérales que le sorgho blanc et le petit mil, avec par ailleurs moins de variabilités de rendements quand la pluviometric change.**
- Les variétés locales de sorgho rouge ont des tiges longues et robustes (3 à 5 mètres de long) qui sont beaucoup plus capables que les tiges de mil ou le sorgho blanc de procurer au paysan suffisament de residus de recolte pour l'alimentation du bétail, pour le feu, pour le paillage et pour la production de fumure organique.
- Le sorgho rouge est utilisé pour la production de la bière locale et en tant que tel constitue une culture de rente très importante dans la région de Manga. Le sorgho rouge a donc sur les autres cultures l'avantage de jouer le double rôle de culture vivriere et de culture de rente.

* Des analyses de rendement ont suggéré que dans l'anneau intermédiaire entre le deuxième et le troisieme anneau ou le sorgho et le mil sont plantés dans des conditions semblables, le rendement du sorgho rouge est autour de 900 kg/ha et celui du *melange* sorgho blanc + petit mil autour de 400 kg/ha (Prudencio, 1983: 189).

** Des analyses de fonction de production lineaire ont suggéré que la productivité marginale d'un kg d'engrais coton est de 11 kg dans les champs de sorgho rouge et de 1,5 kg dans les champs plantés avec mil et sorgho blanc (Prudencio, 1983: 343).

- Le sorgho rouge est adapté à une plus grande gamme de sols dans le village que les autres céréales.
- Les variétés locales de sorgho rouge sont plus précoces que les varietes locales de petit mil et de sorgho blanc et peuvent par conséquent mieux échapper à la sécheresse.
- Le sorgho rouge a un goût moins attrayant que le mil et le sorgho blanc, et pour cette raison ne fait pas l'objet de consommation de luxe, ce qui lui permet de subvenir plus longtemps aux besoins de consommation du ménage.

L'implication majeure d'un tel mécanisme d'ajustement du système de culture à Nonghin par réaffectation de resources est que pour qu'une variété de céreale puisse avoir de fortes chances d'être adoptée dans ce système, elle devrait avoir des caracteristiques plus avantageuses que celles des variétés locales de sorgho rouge à Nonghin. Bien entendu ill aurait été fort utile d'avoir quelque connaissance sur ce mecanisme d'ajustement avant d'élaborer un programme de séléction à l'intention des paysans d'un tel système.*

L'ICRISAT, dans ses recherches sur des variétés resistantes au *Striga* a récemment introduit au Burkina Faso une variété hautement productive de sorgho rouge plus résistante au *Striga* que la plupart des variétés locales de sorgho rouge du pays. Il se fait qu'apparemment c'est dans la région de Manga que cette nouvelle variété de sorgho rouge a remporté le plus de succès auprès des paysans dans le pays.

Conclusion

Les systèmes de production agricoles paysans au Burkina Faso et ailleurs ne sont pas des systemes stagnants incapables de réagir de facon adéquate aux changements dans leurs conditions environnementales. Ils disposent de mécanismes d'ajustement qui leur permettent de s'adapter à de tels changements, et à trouver des solutions pour faire face aux problèmes qu'ils rencontrent. Ces solutions paysannes ne sont peut être pas optimales, mais elles existent et doivent être prises en considération dans tous les efforts de recherche et de développement destinés à venir en aide aux petits paysans. Ceci tout simplement parce que toute solution qui a sa source au sein d'un système pour resourdre un problème particulier de ce systeme est nécessairement déja adapté au système. Par conséquent les chances d'élaborer des technologies et des actions de développement "adaptées" ou "appropriées" sont plus grandes si l'on prend comme point de départ les solutions propres au systeme, en essayant d'abord de comprendre la logique de telles solutions et en essayant ensuite de les améliorer. La probabilite de succès d'une telle approche veritablement de la "base vers le sommet" est probablement plus élevée que celle de l'approche qui consiste à transférer ou à fabriquer de nouvelles solutions et à essayer ensuite de les adapter à des systèmes complexes souvent difficiles à comprendre.

Ceci ne veut pas dire que cette dernière approche devrait être abandonnée, puisque lorsqu'elles sont bien conduites, des tentatives de transfer direct de technologies peuvent souvent aider à comprendre le fonctionnement des systèmes de production. Ceci ne veut pas non plus dire

* Les autres types de réaffectation de resources decrites au debut de la section 3 font également partie du mecanisme d'ajustement de Nonghin.

que des solutions paysannes adéquates existent toujours dans chaque village et sur chaque exploitation agricole au sein des limites géographiques d'un système de production donné. Neanmoins, des villages et des paysans innovateurs existent dans chaque système de production, si bien que les chercheurs aussi bien que les développeurs peuvent apprendre beaucoup de choses en étudiant les réactions des paysans aux changements dans leurs contraintes de production.

A ce propos un demi pas en avant pourrait être accompli à court terme dans le domaine du developpement agricole par l'amelioration du fonctionnement des systèmes locaux de diffusion d'informations techniques et autres parmi les paysans, les villages et les régions, de manière à faciliter le transfert de technologies locales améliorées des paysans les plus progressistes vers les paysans les moins progressistes.*

Les équipes de recherche sur les systèmes de production agricole peuvent aider a l'identification des solutions d'origines paysannes, mais il ne doit pas nécessairement en être ainsi. Tout chercheur thématique basé sur une station peut le faire en sortant de la station de recherche pour visiter un certain nombre de villages et d'exploitations agricoles dans les limites géographiques de la region que couvre son mandat, pour avoir des discussions informelles avec les paysans au sujet des solutions qu'ils utilisent ou proposent pour resourdre les problèmes qu'ils rencontrent. Le chercheur peut être aisément guidé vers les villages et les paysans les plus innovateurs et dynamiques par les agents d'encadrement. Un programme de recherche construit en partie pour tester et améliorer les solutions paysannes existantes aurait certainement beaucoup de chances de succès (adoption). Le developpeur pourrait également suivre le même chemin pour améliorer les chances de succès des programmes de développement agricole proposés.

La solution à laquelle aboutira soit le chercheur, soit le développeur en suivant une telle approche pourrait ne pas constituer une grande découverte technologique comme le souhaitent impatiemment la plupart des chercheurs et des développeurs. Mais cette approche peut déclencher un processus, une démarche de la pensée qui permettra aux programmes de recherches techniques de s'attaquer aux problèmes réels des paysans avec des solutions pertinentes et faisables. Ainsi, la probabilité d'élaborer une serie ou une combinaison d'innovations technologiques appropriées qui au total aurait le meme impact qu'une grande découverte technologique augmentera de facon significative.

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46 Some Experiences of Farming Systems Research in Ethiopia

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Abstract The merits of Farming Systems Research (FSR) to accelerate the generation and dissemination of technologies for increased agricultural productivity, the objectives and stages in carrying out FSR are briefly discussed. An overview of the experiences in FSR at the Institute of Agricultural Research (IAR) is presented and the findings of the research program at Bako and Nazreth study sites are summarized. Major enterprises identified include maize, teff, sorghum and livestock. Shortages in draftpower, dry season feed, labour during critical operations of weeding and harvesting, poor soil fertility are the limiting constraints affecting both crop and livestock production. The results of packages tested indicated that the recommendations developed by the research stations needed prior testing on farmer's fields to include farmer's assessment before releasing the recommendations for wider adoption. Feasible on-farm trials for the identified key problems are planned.

A shift from the present FSR methodology of step-wise and fine-tuning of available technologies to the development of new technology and/or farming systems is suggested as an alternative approach for the drought prone areas.

Introduction

In most developing third world countries it has become apparent that the generation of new technology alone has not provided solutions for helping the rural farmers increase agricultural productivity and to achieve higher levels of living standards. The constraints on adoption of new technology appear to be more complicated than was earlier conceived by researchers. Technology was developed on research stations under conditions quite different from those of the small farmers and therefore in most instances the technology was not adaptable or acceptable to the farmers for whom it was intended.

The problem of generating technologies that are poorly adopted by the small farmers is attributed to the lack of understanding of the conditions under which farmers operated. This has resulted from fundamentally top-down approach to agricultural research and development. Today there is a significant change in the attitude of the scientific community towards small farmers. The presence of several new assumptions or perceptions of the small farm situation resulted in the development of the Farming Systems Research (FSR) approach (Sands, 1985).

The Farming Systems Research evolved in the post Green-Revolution era with the growing perception of the failure of agricultural research and extension institutions to generate and disseminate technologies adopted on a wide-scale by peasant farmers.

These then led to the adoption of the FSR approach to agricultural research by many developing countries in Asia, Latin America and recently in Africa. The FSR has the following major characteristics. It is farmer-based, problem solving process, comprehensive, multi-disciplinary, complementary with commodity and disciplinary research, iterative, dynamic and responsible to society (Shaner, 1982). Most FSR projects have the stages of descriptive and diagnosis, planning of on-farm research, on-farm research and assessment, recommendation and extension. In these stages it attempts to achieve the following specific objective (CGIAR, 1978):

a) To understand the resource context and evaluate the existing farming system as operated by the farmers.
b) To improve problem identification for better research programmes.
c) To conduct research on new or improved practices for possible testing on farms.
d) To enhance the capacity of research organizations to conduct research on priority farming systems problems.
e) To evaluate new or improved practices, assess their benefits and obtain information on the impact they have on small farmers and the problems faced.

With this background the following section will discuss the experiences of FSR in Ethiopia. It is worth mentioning that ILCA is also conducting FSR in its two highland programnme stations (Debre Zeit and Debre Behran). The paper attempts to review the experience in FSR at the Institute of Agricultural Research which has the national mandate to conduct and coordinate agricultural research in the country.

Experiences in FSR at the Institute of Agricultural Research

Historical perspective

The history of FSR in Ethiopia dates back to 1976/77, when the Department of Socio Economics and Farm Management Studies initiated a sort of an out-reach or demonstration programme around Holetta and Bako research stations. The objective of the programme was to demonstrate available recommendations from the research stations to the nearby farming community. It was realized that the recommendations gave no superior results over the traditional practices and farmers were reluctant to accept the recommendations.

Firstly the need to study why farmers do not adopt what the scientists believe and recommend to be good for them was considered very crucial to chart future research strategies. Secondly, it is evident that our knowledge and understanding of the peasant farmer and his circumstances are far from complete. With these rationales the Department initiated multidisciplinary surveys.

Multidisciplinary Farming Systems Surveys

The first multi-disciplinary survey which was different from the conventional farm management survey and emphasized the identification of farmers' problems as perceived by the farmers was launched at Holetta and Bako Farming System Zones in 1977/78. It was later extended to Nazreth in 1979/80, Mekelle 1979/80, Imdibir, Sheno, Ginchi and Dilla-Yirga Cheffe in 1980/81.

These surveys helped to fill the gap in the understanding of the systems. Information on resource utilization and allocation was collected. Major production constraints were identified. Farmers assessment of available technologies was evaluated. The feed-back to the disciplinary and commodity researchers was also valuable.

Preliminary analysis of the surveys indicated the need for testing available technological packages under farmers' management level and evaluate the farmers assessment to get the necessary feed-back. Accelerating the interaction of researchers, farmers and extensionists to understand the farming system was also found imperative.

Three stages were followed in the process:

- Understanding and identifying problems and potentials for increased production through multi-disciplinary surveys.
- Development and selection of simple viable packages based on identified problems in the respective research stations.
- Testing of the packages of innovations on representative, cooperative and accessible farmers' fields and subjecting them to both technical and economic evaluations.

Package Testing

Until the 1984/85 crop season the multi-disciplinary survey conducted has been followed by development of appropriate packages of innovations in the respective research stations or sub-stations and testing them on nearby farmers' fields. The packages of innovations developed mainly included improved varieties, recommended cultural practices, fertilizer types and rates mostly for the major crops in the study areas.

The package testing programme has been conducted on producers, pre-producers and/or Peasant Associations' communal farms. Farmers provided land, labour and purchased inputs like fertilizers. Improved varieties and technical advice are provided by the respective research station staff. Intermitent visits for researchers have been arranged to the test farms. This has helped to bring together the researchers and the farmers on the field. Field days have been organized for research staff, extensionists and farmers of the district.

Data on labour, draft power, material input and output are recorded by the research staff and/or by training literate and active farmers of the peasant associations or the cooperatives. The data collected are analyzed by partial budgeting techniques and the net return per ha is used for testing economic viability. Farmers' response through formal and informal discussions towards the technology being tested throughout the crops' growing stage is one of the measures of social acceptability. Technical viability is evaluated by crops' performance during the growing stage and ultimately by the yield. Meetings were held with concerned and relevant disciplines of the respective research stations to evaluate the results of previous season's and plan and modify the coming season's recommendations.

The packages of innovations developed in the research stations and/or sub-stations and tested on nearby farmers fields and in areas that have similar agro-ecological conditions have been successful in most cases. However, in some areas technologies tested were not acceptable by farmers for one reason or another although they had shown good performance in the research stations.

On-Farm Trials

Given the significant differences between research stations and real farm level conditions, initiating on-farm experiments was found to be a step in the right direction.

Six on-farm experiments were conducted around Nazreth, Bako Holetta and its sub-stations (Ginchi, Addis Alem and Wolmera) and Awassa/Arsi-Negele in 1984/85 crop season. Additional five kinds of on-farm trials were carried in 1985/86. Based on these preliminary results the on-going trials are modified and new trials are proposed for 1986/87. The Department's research programmes have not resorted to only on-farm experimentation. The package development and testing programme is also being carried out in areas where the technologies have got farmers' acceptance.

The on-farm experimentation programme demanded the establishment of FSR teams in the different stations. Previously, the package testing programmes was conducted by the Socio-Economics and Farm Management Department (which until 1984 was composed of only Agricultural economists) in collaboration with the relevant disciplinary researchers. Since the disciplinary researchers have other obligations or commitments, they could not fully participate in this programme. The Department decided to establish FSR teams comprising Agricultural Economists, Agronomists and Livestock specialists where necessary to have fulltime multidisciplinary and functional teams.

Two teams – one at Bako and the other one at Nazreth were established with IDRC assistance since 1984/85. Similar teams at Holetta, Awassa and Gojam are being established through the World Bank Project.

Preliminary Findings of FSR at Bako and Nazreth

As indicated earlier, full-fledged FSR work started at the two sites with IDRC assistance since the 1984/85 season. The Bako mixed farming system zone is high potential, high rainfall area in the western part of the country. It is an area where both livestock and crop production are highly interrelated. The major thrust of the FSR programme there is to identify the crop livestock interaction and, indicate major problems and suggest possible interventions/solutions to increase crop and livestock production.

The Nazreth zone is a semi-arid area in the rift valley characterized by low and erratic rainfall. The objective of FSR programme at Nazreth is also to identify major production constraints in the system and suggest possible areas of research and evaluate available research findings on farmers' fields before they are recommended for adoption in wider scale.

Diagnostic surveys to desribe the systems under study and identify major problems and potentials for increased crop and livestock production were carried out. Secondary information from local sources such as Ministry of Agriculture offices, The Peasant Associations offices were made available. Informal and formal surveys were conducted in the study sites. Based on natural and farmers circumstances five and two target recommendation domains were identified at Bako and Nazreth, respectively. Following is the summary of the diagnostic surveys.

Relevant on-farm experiments for the above mentioned interventions have been identified and some have been implemented last season while some are planned for this crop season.

The small farm system is more complex than commercial farms that most

Table 1 Results of Diagnostic Surveys carried out at Bako & Nazreth

I) *Natural & Biological Circumstances*	*Bako*	*Nazreth*
Rainfall		
– bimodal: small rains	March-April	March-April
: big rains	May-Sept.	June-Sept.
– Annual average	1217mm	600-800mm
Topography	rolling, hilly & mountainous	mainly flat, small hills
Altitude	1380-1740	1400-1680
Soils		
– colour	redish brown, dark redish	brown, grayish, pale-brown
– texture	clay	clay loam, loam salty-loam
– ph	5.5-6.5	7.0-8.0
– organic matter	high	low
II) *Farmer Circumstances*		
Family size	6	5
Area/family	5 ha	3.5 ha
No. livestock/family	6.1	8.5
Ox/family	1.1	2.5
Credit service	very limited	very limited
– Extension	” ”	” ”
– Infrastructure	poor	good
– Access to market	”	”

III) *Enterprise Pattern & End Use*

Bako		*Nazreth*	
Enterprise	*End use*	*Enterprise*	*End use*
1. Maize	Consumption	1. Maize	Consumption
2. Teff	Sale	2. Teff	Consumption/Sale
3. Cattle	Draft power	3. Sorghum	” /Brewing
4. Noug	Mainly cash	4. Livestock	Draft power and sale during crop failure
5. Pepper	” ”		
6. Sorghum	Consumption	5. Haricot beans	Sale
7. Sweet potato	”		

IV) *Major Constraints*

Bako	Nazreth
1. Shortage of draft power	1. Late start and/or early finish of rainfall resulting crop failure and/or very poor yield of long cycle crops maize and sorghum.
2. Poor soil fertility	2. Shortage of dry season animal feed, grazing land and water
3. Labour shortage (during weeding & harvesting)	3. Weeds
4. Lack of improved varieties	4. Poor soil fertility
5. Crop pests (wild animals, stalk borers, weevils, termites)	5. Quela attack on sorghum (particularly on the early maturing and high yielding improved varieties)
6. Animal diseases & parasites (Trypanosomieses, Anthrax, Ticks)	6. Soil erosion due to windy, water, high livestock population
7. Dry season feed shortages (causing low draft power capacity hence delaying plowing and planting, low milk yield, disease susceptibility)	

Table 1 *contd*

V) *Possible Interventions*

Bako	*Nazreth*
1. Introduction of improved management practices of natural pasture, introducing improved forage crops for problems of draft power shortage and low capacity and dry season feed shortage.	1. Introduction early maturing varieties appropriate and cultural practices for maize, sorghum and lowland pulses to minimize crop failures during eratic poor rainfall seasons.
2. Determination of alternative soil management and amendment practices (organic manuring, chemical fertilizers, economical rates and types).	2. Introduction of fodder/forage crops for moisture stress conditions.
3. Improved weed management practices and alternative planting dates for maize or teff to distribute the labour demand for weeding of maize and planting of teff.	3. Chemical and cultural control methods of weeds.
4. Evaluation of improved varieties on farmers fields to assess their acceptance or the reasons for rejecting.	4. On-farm fertilizer trials.
5. Chemical and cultural control methods of pests.	5. Screening bird tolerant varieties of sorghum to replace the present quela susceptible varieties.

of us know. Some of the most important elements leading to this complexity are (Byerlee, 1982):

1. Long growing season which increases the range of potential crops and the possibilities for multiple cropping including intercropping.
1. Unreliable input and output markets uncertain climate; low farm incomes which increases the importance of risk in farmer decisions.
3. Low average productivity of family labour, major factors of production often combined with seasonal labour shortages.
4. Heterogeneity of resources employed by the farm household.

These considerations lead to a wide range of enterprises and production practices for a given enterprise such as the use of more than one variety or planting dates for a given crop. Farmers in the study areas plant more than three types of maize, sorghum or teff depending on their earliness, color or end use. They also change their enterprise mix to avert the risk of crop failure.

Farming Systems Research for Drought Prone Areas: Some Methodological Issues

Many developing countries are adopting different agricultural development strategies to accelerate agricultural productivity. Research and extension efforts concentrated on high potential areas, in the short-run is used as, one strategy. Low potential areas receive minimum attention in the short run and are considered in the long term as they require quite a huge sum of investment which many developing countries cannot afford. This development strategy is adopted by the Ministry of Agriculture in Ethiopia.

Many FSR projects as being implemented to date follow a step wise approach to bring incremental change in production by fine-tuning available research results. However it is high time that research efforts in general and FSR projects in particular should give emphasis to drought prone areas. It is understood that ICRISAT and ICARDA are carrying out basic and developmental research for semi-arid tropics and dry areas, respectively. The centres also have FSR projects as well.

In terms of the African Farming System, two features are important to consider when designing FSR projects for drought prone areas. First, livestock play a central and pervasive role in the functioning and success of the system. Second, climatic variability especially rainfall amount and inter temporal distribution is high. Witness is the present devastating drought affecting most African countries including Ethiopia. Any FSR project in drought prone areas of Africa has then to take into account these important features of the system.

Returns to agricultural research and extension in these areas are very low due to low population density and large areas. High environmental variability across sites and seasons calls for a different approach in FSR. The FSR teams in most cases operate from a station and carry out descriptive and diagnostic work around their respective stations. The teams also execute their on-farm experiments in limited number of locations and few replications. The complexity in drought prone areas calls for a different approach in diagnostic phase, more locations and replications of on-farm trials. A shift from the present step-wise approach in FSR to the development of new farming systems must be considered as an alternative approach.

According to Simmonds (1984), new farming system development has particular relevance to agroecological zones which have changed so rapidly and dramatically due to population pressure and environmental degredation which is the case in drought prone areas. However, socio-economic aspects need to be considered in implementing of new and complex technologies.

Hence available FSR experiences in high potential areas have to be reviewed to develop future FSR programmes for drought prone areas.

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47 The Impact of Drought on Farming Systems in the Semi-arid Regions of Eastern Kenya

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Abstract Small scale rainfed mixed farming systems in the semi-arid environment of Eastern Kenya is discussed in this paper. A characterization of the farming environment as well as variations in the key factors is attempted. Consequences of shortfalls in production for subsistence and response strategies that are employed in coping with the situation are highlighted. Possible research issues for the development of farming in the region are suggested.

Introduction

The semi-arid region of Eastern Kenya receives mean annual rainfall within the 500mm-800mm range in six out of ten seasons. This region comprises agroecological zones IV and V in the Machakos, Kitui, Embu and Meru administrative districts. Total land area under these agroecological categories is 2.52 million hectares, 72 percent of which is in agroecological zone V (see Jaetzol and Schmidt, 1983). Within this region, small scale rainfed mixed farming systems are practised.

The farm units are faced with varying degrees of low productivity and relative resource scarcity. The important resources that are used in farming are land and family labour. Low resource productivity is mainly attributed to the characteristics of the environment and the general low rate of adoption of improved techniques of production into farming operations.

Even during average seasons, farm production barely matches the subsistence requirements of the farm household, so that when drought occurs, the household so affected experiences severe hardship. Immediate responses by farmers include running down of food stores and cash reserves, selling livestock to generate money with which to buy food and temporary outmigration in search of paid employment. Long term measures include outmigration in search of land in other areas and adjustments to the farming systems.

The short-term response of government usually involves mobilization of food resources for famine relief programs. Other measures such as soil conservation, destocking and resettlement of excess population on newly settled land are implemented. Increased research for production technology to enhance the land carrying capacity and reduce the impact of droughts and frequencies of famine are given priority by government.

Features of the Environment

The region lies between 3°S and 1°N latitude and between 37°E and 39°E longitude. Altitude range varies from 700 to 1700 metres above sea level. There are clusters of hill masses scattered throughout the region, and these hill-masses do exert a profound influence on the climate of the region (Jaetzol and Schmidt, 1983).

Climate and Vegetation

Rainfall and temperature are the main aspects of climate that influence the pace and direction of farming in the region. Rainfall tends to be directly related to altitude so that the higher the altitude, the higher the rainfall and the lower the temperature and evaporation demands of the atmosphere.

Eastern Kenya receives two distinct seasons of rainfall, namely October-December (short rains) and March-May (long rains). The most climatically favourable areas receive about 800mm per year while the least favourable areas receive about 500mm per year. Each season receives approximately half of the annual amount, which means that the seasonal rainfall is between 250mm and 400mm. While the distribution of rainfall within the growing season will strongly influence crop performance, maize production of between 0.5 and 1.5 t/ha requires 250mm of rainfall, assuming a low input level of crop management which characterises most of the region (Stewart and Faught, 1984).

The most distinctive features of the natural vegetation are acacia and thorn bushes. Several types of grasses occur in the rangeland (e.g. *Aristida* and *Themeda* spp.). Immediately following the onset of the rains, there is normally a broad-leaved shrub growth and semi-annual grasses underneath the acacia and thorn bush but by the middle of the dry season, the ground is again stripped bare.

The principal soil types of the region are luvisols and acrisols, with small pockets of vertisols (Jaetzol and Schmidt, 1983). The common feature of the soils is that they are low in natural fertility. Most of the soils become too hard during the dry season to work before the onset of the rains. On the more sandy soils, soil capping and impeded drainage are the major problems. The principal problem of the region is the general occurrence of wide stretches of shallow soils.

Most of the region is in the Tana and Athi River basis, both of which drain eastwards into the Indian Ocean. The upper parts of the Tana basin in the Mbeere and Tharaka areas have many permanent rivers, while the lower Tana and Athi Basins have fewer permanent rivers but many seasonal rivers. The problems of availability of water for domestic and livestock use are therefore more acute in the lower areas.

Frequency of Occurrence of Drought

Drought occurs when seasonal moisture deficiencies are such that severe restrictions are imposed on crop establishment, crop growth rates and harvestable yields for biannual crops in one growing season (ISNAR, 1985). Between 1896 and 1984, no fewer than 15 drought periods varying in severity, timespan and geographical extent have occurred in Kenya, with a mean interval of occurrence of about six years (see Table 1). The semi-arid

Table 1. Frequencies of drought in Eastern Kenya

	Frequency of occurrence (once in every 'n' years)	
Type of drought	Long rains	Short rains
Mild	3-4 years	1.8-2.4 years
Moderate	5 years	2.4-4 years
Severe	12-20 years	5.5-9 years

Source: Downing et al., 1985.

areas of Eastern Kenya have had somewhat higher frequencies of drought occurrence.

Socio-economic Features

The density of human settlement is fairly low in zone V and quite high in zone IV. Estimates of land carrying capacity suggest that in zones IV and V, 0.88 hectares and 1.13 hectares are required per person (CID, 1978). According to the 1979 population census and results from other surveys that were conducted in the region, population density in many areas now seems to be in excess of the estimated carrying capacities that have been suggested above (CBS, 1979; Rukandema, 1981, 1983 a and b).

Land Tenure

There are three different categories of land tenure in the region, which include a) trust land, b) free-hold land and c) government land. Trust land is by far the most widespread tenure system. Land under this category is occupied and farmed by subtribes and clans, but legal ownership is with the local authorities until it is demarcated and parcelled out to individual owners through the process of adjudication and registration.

The current trend is towards land registration with freehold title deeds being issued to individuals in order to give them incentives to invest in permanent improvements and pledge the land as security for loans should they wish to do so. The process of registration is not yet complete.

Government land can be leased out for specific purposes. Due to land shortages in the former tribal areas, some people are now moving into this category of land.

The rights of use of land were allocated by clans in all areas of the region, which is still the case in parts of Mbeere, Tharaka and Kitui. While communal grazing of land is common to most districts, the extent of communal grazing varies across districts. However, it appears that the extent of communal grazing is greater in the drier areas of the region, which places these areas at most risk during drought.

Farm Resources

The only significant resources that are used in farming are land and family labour. The majority of farmers own livestock, and in the Machakos area, oxen are widely used in land preparation and weeding. Use of oxen is not as widespread in Southern Kitui, and is virtually non-existent in Mbeere and Tharaka. Rukandema reports that 78 percent of farmers in Machakos and

32 percent in Southern Kitui use oxen draft power in land preparation, planting and weeding, and in land preparation, respectively (Rukandema, 1981; Rukandema *et al.*, 1983 a and b). Because the distribution of land varies across the region, many farmers are faced with relative shortages of land. There is a large majority who own less than five hectares (see Table 2), which is less than the minimum land requirement for an average family (CID, 1978).

Livestock

The majority of farmers keep at least some livestock. Cattle, goats and sheep are common in the whole region, while donkeys are predominant in those parts of the region where the most serious problems of water shortage occur. Livestock products, particularly milk and to a lesser extent meat, form a very important contribution to the diet. In regard to crop production, oxen draft power is widely used in land preparation, planting and in weeding. In fact, total land area under crops, as well as the timeliness with which field operations such as land preparation and weeding are accomplished, depends on whether or not the farmer uses oxen and the condition in which they are at the critical time when they are required. Livestock comprise the farmers' most important stock of wealth that is often resorted to when the need to meet cash expenses arises, such as school fees and off-farm consumer necessities. When shortfalls in crop production occur, livestock have to be sold for money to meet food purchases.

Although the population of the area is very high, more than 50 percent of the members of the households are children who are either too young or of

Table 2 Distribution of land by farm size clss in the semi-arid areas in Machakos and Embu districts, Kenya.

(a) *Machakos District*

Farm Size Group (hectares)	No. of Farms	% of Total
0.10-2.00	60	23
2.10-5.00	180	26
5.10-10.00	180	26
10.10+	172	25
Total:	1108	100

(b) *Embu District*

`t2m9.4t3m2.2t4m9.3Farm Size Group (hectares)	No. of Farms	% of Total	No. of Farms	% of Total
0.10-1.00	392	35	37	7
1.10-2.00	389	35	76	14
2.10-3.00	154	14	77	15
3.10+	173	16	340	93
Total:	1108	100	550	100

Source: Rukandema, 1981 and 1983(b)

Table 3 Major food and cash crops and their distribution

Crop	% Farmers growing					
Food Crops	Machakos	Embu		Kitui		Tharaka
	IV	Kathera	Kamarandi	Kawelu	Kibiuni	Gatunga(V)
Maize	100	90	23	100	100	56
Sorghum	11	56	92	84	87	98
Pearl Millet	1	70	94	32	84	99
Beans	64	31	1	62	39	0
Pigeon peas	100	39	2	97	98	12
Cow peas	91	83	85	100	100	100
Green grams	5	85	85	69	66	99
Cash Crops						
Cotton	75	34	6	25	12	47
Sunflower	9	0	0	8	3	9
Castor	1	0	0	68	86	0

Source: Rukandema, 1981 and 1983.

school age, and hence, cannot be included as part of farm labour supply. These youths have to be fed, clothed, housed, and educated.

Cropping Systems

Three major cropping systems have been identified for areas with different climatic conditions in the region (Bakhtri et al., 1982; Rukandema, 1984). This classification is based on crop types and crop mixtures as well as on the level of mechanization. Intercropping is the main form of cropping practice.

In the climatically more favourable areas, maize, beans and pigeon peas are the major food crops (i.e. agroecological zone IV). Cowpeas and sorghum are grown on a relatively minor scale. Within that system, ox-drawn implements are used in land preparation, planting and in weeding. It is the most productive of the three systems.

In the cropping systems of the drier areas, the main food crops are pearl millet, sorghum, cowpeas and grams (i.e. agroecological zone V). Here, production technology is based almost entirely on handtools. Some kind of shifting cultivation is practised, where crop fields are opened up by cutting down the bush, letting it dry and then firing. Such fields are then grown to crops for several seasons and later abandoned to regrow again.

Sorghum and cowpeas are the crops with the widest adaptation to the environment, while maize and beans are the most preferred food crops. Hence people try to grow maize and beans even where the growing conditions are clearly unfavourable. Cotton and castor in those areas are the most important cash crops.

Intermediate between the more favourable maize and beans and the marginal sorghum and millet areas is a transitional zone where most of the major food crops are grown by a substantial proportion of farmers. Maize, beans, cowpeas, pigeon peas, sorghum, millet and grams are grown in the sub-region. The level of mechanization is moderate. About one third of the households own and use the ox plough for land preparation and in planting. Crop types and their distribution are presented in Table 3.

Livestock feeding is almost entirely dependent on the natural pasture. A large number of farmers supplement this natural grazing with crop residues like maize stover, sorghum and millet straw, mainly during the dry season. From Table 4 it can be seen that stocking rates are fairly high in the region. The recommended stocking rate for the Machakos District is between 2-6 hectares per stock unit (Meyn and Wilkins, 1974). Average stocking rates in the region range between 1.1-3.3 hectares per stock unit. Available feed resources appear, therefore, to be insufficient for the requirements of livestock in the region (Neunhauser *et al.*, 1983). The major consequences of the relative shortage of feed must be over-grazing and a chronic loss of condition of the animals. Over-grazing leaves the ground bare so that when rains come, there is excessive run off from the grazing land causing severe soil erosion. Inadequate feeding results in loss of condition of the animals with its negative impact on productivity, animal health and reproductive performance.

Implications of Drought

Pre-drought

The rate of population growth in the semi-arid region of Kenya is approximately 4.8 percent a year, which exceeds the national rate of 3.8 percent. With an already high level of population density, the implications for the region are decreasing farm size through continuing sub-division of land, and hence, increasing land use intensity.

Since cropping in this region is characterised by a relatively high degree of risk, farmers are reluctant to purchase (off-farm) inputs, such as artificial fertilisers. Further, much of the region has been cropped continuously to the same crops for between 20 and 30 years. Hence, many farmers are now experiencing declining crop yields, with temporary compensation being attempted through increasing livestock numbers. In recent years, this has resulted in grazing pressures outstripping sustainable stocking rates for the region.

Given the bimodal distribution of rainfall, the associated seasonal cropping practice and demands placed on livestock means that reductions in the extent of ground cover place soils at risk to erosion at the onset of both the long rains and the short rains. The combination of shallow topsoil and high rainfall intensity following drought has a potentially depressing effect

Table 4 Herd and flock sizes and stocking rates in semi-arid areas of Eastern Kenya

	Average no. of livestock units* per household					
Location	Machakos	Embu		Kitui		Tharaka
		Kathera	Kamarandi	Kawelu	Kibiuni	Gatunga
Agroeco zone	IV	IV	V	V	V	V
Cattle	4.20	2.40	2.40	6.60	7.60	4.80
Goats	1.20	0.96	1.08	1.32	1.20	2.28
Sheep	0.36	0.12	0.24	0.84	0.48	0.84
Total	5.76	3.48	3.72	8.76	9.28	7.29
S R(Ha/1su)	1.10	1.66	3.30	1.08	3.20	1.20

* one LSU = 250 Kg liveweight.

on the productive capacity of the region, unless the fragile balance of the ecosystem is recognised and managed.

As stated earlier in the paper, under average seasonal conditions, farm households manage only to sustain themselves, with few cash reserves to meet other (non-food) needs (i.e. clothing, education). Generally, farmers have to dispose of some stored grain or livestock to meet those needs. In addition, a relatively high proportion of farm households have at least one member engaged in casual or permanent off-farm work which represents a severe drain on farm labour supplies, particularly in a region where the dependency ratio within the farm household is high. This again suggests that the risk of crop failure requires farmers to adopt appropriate risk management strategies (i.e. off-farm work, maintaining livestock numbers) in order to achieve the goal of ensuring a stable supply of food for the household. Any development such as drought that depresses the delicate balance achieved under average seasonal conditions must carry with it severe repercussions for the farm, the farm household and the region that will continue to affect post-drought recovery into the medium term, and even into the longer term in some cases.

Drought

Under the climatic condition of drought, the first evidence is poor crop establishment and then crop failure. With such a result, the farm household is forced to draw on food reserves, if available, and acquire food from alternative sources once those reserves are depleted.

As the season deteriorates, degradation of the pasture base follows, leading to a decline in animal nutrition. With that decline there occurs an increase in the incidence of diseases among livestock, and possibly death as farm families trade-off purchases of veterinary supplies. Even if the drought should occur for only one season, the decline in animal nutrition inevitably results in poor livestock performance in the ensuing season, particularly among animals used for draft power. The net effect for the next cropping season is slippage in the timeliness of cropping operations, with its subsequent second-round effects.

Concurrent with the reduction of livestock fodder supplies is an accelerating deterioration in available water. As water supplies dry out, family members need to travel longer distances to collect water for the farm household. Also, livestock need to be driven similar distance for water. In both cases, additional energy is being expended under declining planes of nutrition. In the drier areas of the region, the higher incidence of communal grazing means that the ecological stability of these relatively more fragile areas is placed at greater risk.

Following the short-fall in crop production that occurs as a result of drought, there is an increase in crop prices. However, with deterioration of the pasture base and available water supplies, together with the need of the farm household to sell livestock to generate cash to buy food, more livestock are placed on the market. The net result is a decline in the prices received for livestock. Hence, as farmers are faced with increasing crop prices and declining livestock prices, they are forced to sell more livestock units to meet basic requirements than otherwise would be necessary under normal conditions. Often it is the productive capital component of the livestock base which farmers have to sell (i.e. cow, draft oxen).

Post-drought Recovery

As a result of the reduction in farm reserves that occurred during the drought (i.e. stored food, livestock, cash), farmers do not have the means to restore the productive capacity of the farm immediately following the return to normal seasonal conditions. The general reluctance by farmers to dispose of livestock during drought, except for the reasons stated, is probably best understood in such terms. Further, with low livestock prices ruling during drought, most farmers realise that they simply will not have the cash reserves available to restock following the drought. At the same time, the great unknown during drought is the duration of the drought such that livestock represent the main source of security to farmers in terms of meeting future food demands.

During drought, many farmers are forced to consume their seed reserves. This consequence of drought is particularly severe on farmers who had acquired or purchased improved varieties before the onset of drought. Unfortunately, the relatively low level of usage of such improved crop varieties among farmers following drought may be misinterpreted as a low rate of adoption (non-acceptance) of such technology. While farmers may be interested in growing such varieties, in the short-term post drought farmers may not be able to purchase such varieties following their run-down of (cash) reserves or they may be unable to acquire those varieties because of their general unavailability.

The point which emerges from the preceding discussion is that the consequences of drought do not conclude with a return to normal season conditions. There are important lagged effects on production. First, there is a long-term reduction in the productive capacity of the soil through erosion. Second, in the ecology of rangeland through the invasion of inferior species. Third, the reduction in the livestock base is often evident in reduced draft capacity and shortfalls in milk production, where the latter may have represented an important source of cash income to the farm household. Fourth, serious lags in crop production are likely to result from consumption of capital assets (i.e. improved varieties of seed, livestock etc), decline in soil fertility levels and untimeliness of cropping operations.

Research Needs

Experience with the past drought raises several issues for research. First, despite the severe impact of drought on rural households, there appears to be a general lack of research on the effect of drought on-farm. On-going research into systems of management employed by farmers during drought would provide useful insight to issues for technical research. Some quantitative assessment of the strategies adopted by farmers would represent an important contribution in this regard. Similarly, the constraints to post-drought recovery warrant investigation (e.g. the unavailablity of improved seed varieties).

Second, as far as crop production in the semi-arid tropics is concerned, there is a continual need for research into better adapted crop varieties. While it may be a pipe-dream to talk of drought resistant crop varieties for the semi-arid zone, the demand for varieties with improved tolerance to drought is evident (i.e. improved adaptation, shorter growing season etc).

Third, on the assumption that the rates of adaptation for improved crop technology packages will increase and lead to levels of production that exceed basic requirements of the rural household in a normal year, there is a need for improved techniques of on-farm grain storage. Such avenues for research may be regarded as options for farmers to maintaining large numbers of livestock.

Fourth; in a similar vein to the above, on-farm fodder requirements for livestock during drought suggest that alternative forms of fodder banks need consideration. That is, perennial legumes with high degrees of drought tolerance may have a potential contribution as fodder banks on-farm. Such fodder banks could also play an important rôle in lessening the extent of soil erosion.

Fifth, the water requirements of the farm household and of livestock are well recognised. However, it is also recognised that the provision of improved water facilities in semi-arid areas is a major problem.

Summary and Conclusions

The purpose of this paper has been to provide an overview of farming systems within the semi-arid areas of Kenya, with a view to analysing the impact of drought on farm households and on the longer-term ecological stability of the region. Even under normal seasonal conditions, the stability of the region is finely balanced, with food supplies just meeting demands for food. In recent years, the region has witnessed a rising population growth rate and increasing land use intensity for both crop and livestock production. The occurrence of drought causes major disruption to farm-households through its short-term and longer-term effects on production activities. In the short-term, farmers experience loss of crop production and deterioration of the natural pasture base. Capital assets are disposed of to meet the immediate demand for food by the farm household. In the longer-term, lags of production following drought result from a general lack of cash reserves, reduction in the capital base, degradation of soil and pasture resources, and the difficulties faced by farmers in restocking their farms.

Although several issues from research emerge for a consideration of past drought occurrences, recent experience does suggest a need for monitoring the activities of farmers during drought. This includes their drought management strategies and responses to resource use. Such analysis is important in providing directions for policy to facilitate adjustment strategies for farmers to meet future occurrences of drought.

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TECHNOLOGY DEVELOPMENT AND TRANSFER

48 Technology Development to Increase Cereal Production in the (WASAT) West African Semi-Arid Tropics

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Introduction

The West African semi-arid tropics (WASAT) is one of the poorest regions in the world with 1984 per capita yearly incomes for the area ranging between $US80 and $US300 (McNamara, 1985). The region as a whole has a balance of trade and balance of payments problem. The economies depend heavily on foreign aid, borrowing and worker remittances. People (labor) are one of the biggest exports from the region – an estimated 25% of the labor force of Burkina Faso works in neighboring non-WASAT areas. The region exhibits a bottom-heavy age pyramid with country population growth rates ranging between 2.5% and 3.0% per year and a fertility rate averaging 6.5 children per adult female. The growth in per capita food production (1971-1984) for the region as a whole is negative while levels of food imports (largely from donor agencies) have increased dramatically over the last 25 years (McNamara, 1985; Paulino and Mellor, 1984). The current trend in population growth (doubling in about 20 to 25 years) and the decreasing of the per capita food production in the region has led many to a Malthusian perspective about the future of the WASAT.

The specific objective of this paper is to present recent research findings from the WASAT – in particular from Burkina Faso – which suggest a Malthusian perspective can be averted. Although some areas of the WASAT are experiencing a decline in cereal yields and changes in the traditional bush-fallow farming systems because of increasing population pressure, several on-farm evaluated technologies have been shown to be both agronomically and economically feasible in increasing cereal production – the dominant agricultural activity of the areas. The second objective of the paper is to prioritize the technologies and farm management techniques presently being proposed for the WASAT in an attempt to provide research, extension, and government policy guidelines. The paper makes use of the recent research experiences of Burkina Faso as a development model that is applicable to similar agroclimatic zones (500 to 900mm rainfall zones) and farming systems in many of the WASAT countries.

Farming Systems and Major Production Constraints in the WASAT

The main constraints to increased cereal yields and production in the WASAT in the future are: 1) climatological and physical conditions exhibited by low soil fertility, low soil water retention and an unpredictable level and distribution of rainfall, 2) labor and land endowment shortages: labor shortages in the critical, peak-labor period of planting and weeding and limited access to land in the old settlement areas, 3) poor to nonexistent input and product marketing infrastructure (outside of cotton growing regions) and 4) the inadequate to nonexistent information services. Cereal production is the dominant agricultural activity – 90 to 95% of all cultivated land is in cereals (Lang, et al., 1983). The staple crops of sorghum, millet and maize receive the highest priority of land and labor resources. Drought tolerance of the crops are matched with soil fertility and toposequence. Maize is planted on the relatively high-fertility compound land (which receives manure and organic wastes), sorghum on the lower more fertile part of the toposequence and millet further up the toposequence on the poorer land. Millet can be found grown in the next higher soil fertility gradient than that dictated by its drought tolerance ability but maize and sorghum are rarely grown on a lower soil fertility gradient. Thus, as the soil fertility gradient changes, different cropping and management strategies are undertaken by the farmer – referred to as farmer management rings (Matlon, 1985; Stoop, *et al.*, 1982).

The poor fertility soils, erratic rainfall distribution and low soil water retention has led to highly variable between-year yield responses to land substituting inputs. This in turn leads to a high risk of losing the cash outlay for purchased inputs. Thus, farming systems are characterized by bush-fallow systems that rely on available land and family labor inputs with little utilization of non-farm or purchased inputs (Matlon, 1985; Lang, *et al.*, 1984). With the lack of demand, the input and product marketing infrastructure for farming systems with high input levels and large cash sales have not yet been developed.

The present man/land ratios in the region, which generally average 15 persons per sq km (World Bank, 1985), are extremely low when compared with up to 600 persons per sq km in Asia (McNamara, 1985). The poorer agricultural resource base of the WASAT however cannot support the high man/land ratios of Asia (Matlon, 1985). A case in point is the Central Plateau of Burkina Faso with man/land ratios of 60 persons per sq km (World Bank, 1985) and parts of the northern region of the country where high man/land ratios relative to the resource base have already caused a change in the traditional bush-fallow farming system of cultivating land for 3 to 5 years and then leaving it idle for a decade or more to restore the soil fertility. In many of the older settlement villages, increased population has meant limited access to new land, a shortening of the fallow rotation period and the cultivation of more marginal land (Norman, *et al.*, 1981; Dugue, 1985). In the village of Nedogo, Burkina Faso, many fields have been cultivated as long as the farmer can remember (FSU/SAFGRAD, 1983). The shorter and at times non-existent fallow period, in combination with the farm management practice of burning or removing all plant material for household use and animal feed, exhausts the soil. Deforestation and the increasing threat of desertification in the 350-600mm rainfall Sahelo-Sudanian zone has accompanied the increase in population and the change in the farming system (World Bank, 1985). As more pressure is put on the land for food production, without technological intervention soil deterioration will increase and result in further lowering of yields.

The farming systems of the Central Plateau and of those parts of the northern region of Burkina Faso which exhibit a land deficit are in contrast to most of the other regions of the WASAT which are characterized by a frontier model of agriculture with surplus land. For example, the eastern region of Burkina Faso (man/land ratios of 15 persons per sq km) has surplus land and follows the bush-fallow system of cultivation. However, even on the frontier, as population pressure increases, a phenomenon similar to what is now taking place on the Central Plateau of Burkina Faso would be expected to take place throughout the region.

Sequential Technology Adoption

With respect to technological intervention, the largest impact on yields and production comes about when various methods (technologies) are used in combination, i.e. in a "package". Evidence exists, however, that farmers do not necessarily adopt technologies as a package but rather adopt single technologies or "clusters" of technologies en route to total package adoption (Byerlee and Hesse de Planco, 1986; Mann, 1978). The farmer's strategy seems to be to adopt the technologies of the package sequentially based on availability, technical viability in the field, economic profitability and risk considerations, and the resource endowment fit of the technology (i.e., labor and land constraints) within the farming systems. The technologies within the package that best exhibit the above attributes will be selected first by the farmer. Other technologies will be added only after the farmer has experience with the already adopted technologies and, again, when the above attributes dictate. Thus, while farmers can be presented with a package of technologies, there seems to be an agronomically and economically logical sequence by which technological adoption will occur. Information on the likely adoption pattern sequence of proposed technologies is important for focusing research, extension, and government programs.

Proposed Technologies for the WASAT

The purpose of this section is to outline the technologies and farm management techniques that have been proposed for alleviating the production constraints in the WASAT. As each technology is discussed, it is evaluated as to the feasibility of its utilization by farmers in the short run (0 to 5 years), the intermediate run (5 to 15 years), and the long run (presented in Table 1). The farmer's sequential adoption strategy criteria are used to evaluate each technology, i.e. the criteria of technical viability in the field (based on on-station and on-farm research), economic profitability (based on budget analysis, Benefit-Cost ratios, and whole farm modelling), risk considerations (based on research trials, incidence of cash outlay loss), and the fit of the technology within the farming systems (based on whole farm modelling, labor data analysis, farmer survey response).

The research that has been carried out in the WASAT aimed at alleviating climatological and physical constraints and labor endowment shortages is discussed under the headings: 1) soil fertility/water retention technologies, 2) labor-saving technologies, 3) improved varietal research, and 4) crop associations.

Table 1 Present technical and economic feasibility and time frame of proposed technologies and farm management practices for the WASAT.

Technologies and Farm Mgmt. Practices	Present Agronomic and Technical Feasibility: On-Station Research	Present Agronomic and Technical Feasibility: On-Farm Research	Present Economic Feasibility	Comments
	Available technologies for the short run			
Tied ridging (manual)	+++[1]	+++	***[2]	Very labor intensive
Diguettes/dikes	[3]	+++	**	Require materials (i.e., rocks)
Complex fertilizer	+++	++	*	Risk of losing cash outlay
Animal traction	[3]	++	*	Preconditions (see text)
Mechanical ridge tier	+++	++	***	Requires animal traction
	Potential technologies for the intermediate run			
Rock phosphate	+	–	–	Solubility & application problems
Improved varieties	++	+	–	Requires upgrading of physical environment
	Potential technologies for the long run			
Manure/composting	+++	++	***	Small and finite supply
Mulch	+++	++	**	Small and finite supply
Plowing/green manuring	++	++	–	Poor draft animal health
Herbicides	++	++	–	Further research required[4]
Biol. nitrogen-fixation	+	–	–	Further research required
Crop associations:				
– intensification	++	+	–	Requires upgrading of physical environment and improved varieties. Labor and management intensive.
– alley cropping	++	+	–	

[1] +++ High degree of feasibility – research supports a very good agronomic response or is technically very feasible.
++ Feasible – good agronomic response or technically feasible.
+ Limited feasibility – agronomic results often inconsistent.
– Not feasible – little evidence to support a good agronomic response or technical feasibility.

[2] *** = Highly profitable at present.
** = Profitable at present.
* = Not always profitable at present.
– = Not economically feasible at present.

[3] Not researched at the on-station level.

[4] Can be feasible for sole cropping but problems with mixture of broad and slender leaf plants in crop associations.

Soil Fertility/Water Retention Technologies

Tied Ridges

Tied ridges (on-station and on-farm research) have been shown to significantly increase yields (Nicou and Charreau, 1985; Dugue, 1985; Rodriguez, 1982; Ohm, *et al.*, 1985a and 1986b)[4]. FSU on-farm, researcher-managed trials (TR constructed both at, and one month after, planting) and farmer-managed trials (TR constructed 4-6 weeks after planting) have shown significant yield increases and economic returns to the additional labor required to do TR for maize, sorghum (Table 2, column 2) and millet (FSU 1982 Annual Report, 1983; Lang, et al., 1984; and Ohm, et al., 1985a and b). Manual tying of ridges is very labor intensive. The manual tying of animal-traction-made ridges requires at least 40 man hours/ha (with very efficient laborers) and on the average 75 man hours/ha, whereas constructing TR completely by hand requires at least 100 hours/ha (Ohm, et al., 1985b).

Tied ridges construction has the advantage that no cash outlay is required if family labor is utilized. However, a survey of the adoption of technologies by farmers in FSU villages indicated that the number of farmers constructing tied ridges and the hectarage of tied ridge construction outside the trial plots were small – an average of 0.32 hectares/farmer with the largest being 1.0 hectare (Ohm, *et al.*, 1985b). When questioned, farmers indicated that they would like to construct more TR but they did not have sufficient family labor. Hiring from an outside labor pool is limited at the time tied ridges must be constructed because the active labor force of all households is fully occupied with work in their own fields. Linear programming representative farm models (Table 3, column 2) also indicate that labor availability constraints prevent the manual tying of animal-traction-constructed ridges from being utilized on the entire farm.

Another limitation is that tied ridging does not work well on sandy soils because the ties tend to break down in heavy rain. Nevertheless, an estimated 40% of the presently cultivated land in Burkina and 15% in Mali appears to be suitable for tied ridging. This represents 1.2 million hectares (Burns, 1985). Tied ridges have been shown to be both agronomically and economically feasible as a technology applicable at the present time to increase cereals production in the WASAT. Howewver, the labor constraint requires a search for labor saving technologies.

Diguettes/Dikes

There are various water conservation/erosion methods in addition to tied ridges that are or could be used in the WASAT. The construction of diguettes, although not as effective in retaining water as tied ridges, is a water conservation method that has been investigated. Diguettes are

[4] Tied ridges (TR) are small depressions made between crop rows either by hand or by a combination of animal traction and hand tillage. When done by hand, depressions 32cm long × 24cm wide × 16cm deep are made between the rows spaced 1½ meters apart. When constructed with animal traction, the fields are first ridged with a cultivator (houe manga) equipped with a middle sweep to create a furrow which is then followed by hand tillage to make a 16cm high ridge perpendicular to the furrow every one to two meters. The depressions catch and hold water after a rain and increase water infiltration and retention. Due to the larger water holding capacity of animal traction tied ridges, water retention ability is greater than that of manually tied ridges.

Table 2 Economic analysis of farmer-managed trials of sorghum with fertilizer and tied ridges, Nedogo and Diapangou, 1983 and 1984.

	Treatments[1]			
	C	TR	F	TR,F
	Nedogo: 1984, Manual Traction			
Grain yield, kg/ha[2]	157	416	431	1652
Yield gain above control, kg/ha	–	259	274	495
Gain in net revenue, FCFA/ha[3]	–	23,828	13,275	33,607
Return/hr of additional labor, FCFA[4]	–	238	140	172
% farmers who would have lost cash	–	0	27	9
	Nedogo: 1983, Manual Traction			
Grain yield, kg/ha	430	484	547	851
Yield gain above control, kg/ha	–	54	117	421
Gain in net revenue, FCFA/ha	–	3,510	−2,285	17,475
Return/hr of additional labor, FCFA	–	35	1–	90
% farmers who would have lost cash	–	0	66	0
	Diapangou: 1984, Donkey Traction			
Grain yield, kg/ha	498	688	849	1,133
Yield gain above control, kg/ha	–	190	351	635
Gain in net revenue, FCFA/ha	–	17,480	20,359	46,487
Return/hr of additional labor, FCFA	–	233	214	273
% farmers who would have lost cash	–	0	21	0
	Diapangou: 1983, Donkey Traction			
Grain yield, kg/ha	481	522	837	871
Yield gain above control, kg/ha	–	71	356	390
Gain in net revenue, FCFA/ha	–	6,532	20,819	23,947
Return/hr of additional labor, FCFA	–	87	219	141
% farmers who would have lost cash	–	0	16	12

Source: Ohm, et al., 1985b and Lang, et al., 1984. Similar results were obtained at three other sites in Burkina.

[1] C = Control (no tied ridges or fertilizer); TR = tied ridges constructed at second weeding; F = 100 kg/ha 14-23-15 applied in band 10-15cm from row at first weeding plus 50 kg/ha urea applied in pockets 10-15cm from seed pockets at second weeding.

[2] The standard error and CV % (in parentheses) starting with Nedogo, 1984 and continuing through to Diapangou, 1983 are 75 (43), 121 (29), 46 (18), and 43 (22), respectively.

[3] Net Revenue = yield gain × grain price (65 and 92 FCFA/kg in 1983 and 1984) minus fertilizer cost (62 and 78 FCFA/kg for 14-23-15, and 60 and 66 FCFA/kg for urea in 1983 and 1984 – fertilizer prices are subsidized 40 to 50%). Includes interest rate charge for six months at rate of 15%. 1 U.S. dollar = 381 FCFA in 1983 and 436 FCFA in 1984.

[4] Net Revenue + additional labor of tied ridging and fertilizer application. Manual and donkey traction require 100 and 75 hours of additional labor/ha for tied ridging respectively. Fertilizer application requires 95 additional hours/ha.

barriers 10 to 15cm high mainly made of rocks and placed on field contour lines 10 to 15m apart. The barriers are permeable and slow rainfall runoff to allow for increased infiltration. They have improved water retention and significantly increased yields in the northern (Yatenga) region of Burkina (Wright, 1985). This technology has the advantage that it can be constructed in off peak labor periods with family labor and is not as labor intensive as tied ridging. However, rocks (the principal material) or other material in some regions are not available to construct the diguettes. Economic analysis indicates that the returns in the first year alone are greater than the labor bill (at the going wage rate) of constructing the diguettes. In Burkina Faso, local government agencies have constructed large dikes and barriers to control water flow at the village level. Although diguettes and other forms of water retention and control require further research, the large dikes and diguettes are technologies that could be used at present.

Complex Chemical Fertilizers

Under on-station and on-farm conditions, significant yield increases for maize, sorghum and millet have been obtained using complex mineral fertilizers (Pieri, 1985; Ohm, *et al.*, 1985b; FSU Annual Reports). Yield response to fertilizer is, however, highly variable between sites and years (Spencer, 1985). Nevertheless, some researchers suggest that continuous cropping using chemical fertilizers is potentially possible in the WASAT (see Pieri, 1985 p. 77 for a literature review and references). Decreases in yield and fertilizer efficiency, however, have been observed after two to five years of continuous cropping where organic matter has not been incorporated into the soil (Pieri, 1985).

In Burkina Faso, on-farm researcher-managed trials indicate that the response of maize yields to fertilizer on the relatively high fertility compound soils was not economically profitable (1982 FSU Annual Report, 1983). On-farm farmer-managed trials indicated that fertilizer can be profitable when using fertilizer alone on sorghum (Table 2, column 3).[5] There is, however, considerable risk for the farmer of losing the cash outlay when fertilizer is used alone as demonstrated by the percentage of farmers who would have lost cash in Table 2, column 3. Both yield and profitability substantially increase, however, when tied ridges and fertilizer are used in combination as indicated in Table 2, column 4. Also, as shown in column 4, the risk of losing the cash outlay from the purchase of fertilizer substantially decreases when fertilizer and TR are used in combination. Fertilizer in combination with TR for millet on millet land has also been shown to be profitable with only a moderate risk of farmers losing the fertilizer cash outlay (Ohm, *et al.*, 1985a).

A survey of four FSU villages in Burkina indicated a range of fertilizer use on cereals from zero farmers in the sample of the northern village of Bangasse to 33% of the farmers in the southern village sample from Poedogo which has better land and higher rainfall. In the more northern region, fertilizer use is riskier due to lower rainfall. Average hectarage fertilized in the villages that used fertilizer ranged from 0.34ha at Nedogo to 3ha at Poedogo (Ohm, *et al.*, 1985b).

The evidence to date on fertilizer use in the WASAT suggests that complex fertilizers are a technology that can be used at present but yields are highly variable and the incidence of fertilizer cash outlay loss by farmers is high unless combined with a water retention technique such as TR. The risk of losing cash decreases in the higher soil fertility and higher rainfall areas. The number of farmers losing cash decreases substantially when TR are used in combination with fertilizer as compared with the fertilizer only strategy.

Indigenous Rock Phosphate

The benefits from using indigenous rock phosphate deposits in the area are potentially appealing in terms of logistics, transportation cost advantages,

[5] All the FSU economic analyses have been carried out using subsidized fertilizer prices (40 to 50%). Clearly, the economic profitability would be lower and the incidence of fertilizer cash outlay loss greater utilizing unsubsidized prices.

and foreign exchange savings. Workable deposits occur in Senegal, Mali, Niger, Togo, Benin, Nigeria, and Burkina Faso. On-station and on-farm trials have, however, found the rock phosphate to have solubility problems (IFDC, 1985; Pierei, 1985). The combination of the low P release in a water-soluble form that is readily available for use by plants and the low P-sorption capacity of the WASAT soils have resulted in poor agronomic performance from rock phosphate applications. There is little or no potential for direct applications of WASAT rock phosphate with the exception of the Mali (Tilemsi) and Niger (Tahoua) deposits (IFDC, 1985).

Two methods are used to increase the agronomic effectiveness of rock phosphate. One method is to highly granulate the rock and the other method is acidulation. Even when highly granulated the agronomic effectiveness is low and several years of consecutive applications are required before significant yield increases are observed (IFDC, 1985; FSU Annual Reports). Even when agronomically effective after several years of application, benefit-cost ratios are low and are lower than other sources of phosphorus (IFDC, 1985). Four years of FSU on-farm, farmer-managed trials in Burkina Faso using highly granulated Burkina rock phosphate (100 kg/ha rock phosphate with 50 kg/ha urea applied each year on the same plots) indicated low benefit-cost ratios. Benefit-cost ratios of less than one with a 50% subsidized rock phosphate price were obtained (unpublished FSU data). In the same experiment, benefit-cost ratios of 1.3 were obtained from a rock phosphate tied ridging treatment but the benefit-cost ratio decreased to 0.69 when unsubsidized prices were used. FSU cooperator farmers did not like using the rock phosphate due to its poor agronomic performance and application problems caused by its highly granulated form. Research on the agronomic effectiveness of partially acidulated rock phosphate in the WASAT has given conflicting results (Batiano, *et al.*, 1985). Inconsistent results were obtained by FSU with 50% acidulated Burkina rock phosphate in a one year, on-farm, researcher-managed trial with sorghum and millet (Ohm, *et al.*, 1985a). The partially acidulated rock phosphate is also highly granulated.

Few economics studies of acidulated rock phosphate are available for the WASAT. When compared with single superphosphate, the relative economic performance of acidulated rock phosphate on millet in Niger is generally lower but is not consistent across sites or years (IFDC, 1985).

To be agronomically and economically feasible, the solubility problem of rock phosphate will have to be overcome. Once rock phosphate becomes agronomically and economically feasible, fertilizer plants and distribution networks would require several years to develop. Thus rock phosphate appears to be a technology which is most appropriate in the intermediate run.

Animal Manure and Composing

Manure and compost are already being used effectively on fields near the compound although application and composting techniques could be more efficient (Pieri, 1985, Table 11). The principal constraint to the increased use of manuring and composting is their finite supply. Few organic waste materials are left once the household and animal feed requirements are met. Cattle are grazed on fallow land away from the living quarters and the labor involved with confined rearing of animals is too great. Cattle are also entrusted to herders because of feed shortages close to the village – as fallow land declines in the old settlement areas, it will be increasingly difficult to support cattle near the village and in the area in general. While animal manure and composting are agronomically and economically feasible for use around the compound area at present, they do not represent farm management practices that will substantially increase cereal production in the WASAT in the short and intermediate run because of their finite supply. Their potential will only be realized in the long run when the farming system evolves from the dominant cereal-based system to a more intensive cereal-forage/cash crop system that is able to support more livestock near the village.

Mulch

Crop residue mulch can reduce rainfall runoff and increase water infiltration but sorghum and millet stalks in raw or compost form may add little to soil fertility (Pieri, 5, p. 91). As with manure, the principal limiting factor of mulch is its finite supply – especially in the northern half of the WASAT. The demand for its use as animal feed, fuel and construction material leaves most fields bare by planting time, and when it is not all used, the prevalent custom is to burn it. Even when not used for other purposes, crop residues (3 to 5 T/ha) are not sufficient by themselves to increase soil fertility and water retention capacity appreciably.

Plowing/Green Manuring

Significant yield increases from on-station and on-farm research have been observed from deep plowing and tillage practices which change the structure of the soil; allowing better root establishment and improved water infiltration and storage (Nicou and Charrerau, 1985; Dugue, 1985). Most tillage in the WASAT is done by shallow, manual cultivation (85% of farmers) or by shallow, animal traction cultivation. Little pre-plant plowing or tillage is done because of the need to plant soon after a rain (within 2 to 3 days). The soil is generally too hard and the animals too weak at this time of year for effective plowing to take place before a major rain. Green manuring can also increase the fertility of the soil and add to the water retention capacity of the soil (Pieri, 1985). This practice also requires deep plowing to incorporate the plants into the soil. Because of the substantial draft power requirement this can only be done by healthy, well fed double ox teams. This type of draft power will be available only in the long run when the farming systems can support high level maintenance of the draft animals.

Labour Saving Technologies

Animal Traction

An estimated fifteen percent in the WASAT use animal traction – mainly for transport, shallow weeding, or shallow land-preparation plowing (Matlon, 1985). Farmers in general use only one mechanized operation and do not use animal traction for all the agricultural activities of soil preparation, planting and weeding (Jaeger, 1983). To date, animal traction usage in the WASAT can be characterized as land using (extensive). Some studies have reported significant farm area expansion from animal traction usage. Animal traction can perform weeding 6 to 7 times faster than manual weeding (Jaeger and Sanders, 1985). Increased yield effects have been reported in the literature (mainly from plowing) but the yield effects are generally small (Binswanger, 1978).

In spite of potentially high rates of return, animal traction adoption rates are low in the WASAT. Present internal rates of return of 10% in old settlement areas (Nedogo) and 20 to 30% at the frontier (Diapangou) have been estimated but higher rates of return could be achieved by higher utilization rates – utilizing animal traction units for over 30 days/year (Jaeger, 1983). Higher utilization rates can be obtained by expanding the number of mechanized agricultural operations. Problems of obtaining high utilization rates stem from: small size farms, inappropriate and/or incomplete sets of implements, poor animal health and poor management (Jaeger and Sanders, 1985).

To obtain the full benefit of mechanization, first-time users must learn to use animal traction units quickly. However, learning curves can be as long as 5 years (Jaeger and Sanders, 1985). Farmer and animal training through extension and an improved market for trained draft animals could lead to shorter learning curves.

Animal traction is technically and economically feasible for use in the

Table 3 Whole farm modeling analysis of tied ridging only with donkey traction, Central Plateau, Burkina Faso.

		Tied-ridging technology[1]		
			Tied with machine	
Variable	Traditional management (donkey)	Tied by hand	Two passes	One pass
	hectares			
Total area cultivated	5.5	5.6	5.6	5.5
Maize				
Traditional	.20	–	–	–
With tied ridges	–	.20	.20	.20
Red sorghum				
Traditional	.60	–	–	–
With tied ridges	–	.60	.60	.60
White sorghum				
Traditional	.80	.51		
With tied ridges		.29	.80	.80
Millet				
Traditional	3.18	3.15	3.15	1.84
With tied ridges	–	–	.33	1.64
Peanuts	.76	.85	.53	.43
	Total cereals production	kgs		
Per household	2103	2436	2651	2737
Per resident[2]	150	174	189	196
Net farm income[3]		000's FCFA		
Per household	215.3	246.2	253.5	262.2
Per worker[4]	30.8	35.2	36.2	37.5

[1] Labor times of 75 man hours/ha for tying of the ridges by hand, 20 man hours/ha to machine tie with two passes, and 2 man hours to machine tie with one pass. Yield estimates in kgs/ha for traditional practices and the technical intervention of tied ridging are as follows: maize (1090 to 1730), red sorghum (672 to 940), white sorghum (472 to 660), and millet (320 to 415). 1985 fertilizer and grain prices were used.

[2] Based on 14 residents/household.

[3] Annualized cost of 4,400 FCFA for tied-ridging machine subtracted in columns 3 and 4.

[4] Based on 7 active workers/household.

short run and has the potential for higher rates of return if the preconditions of higher utilization rates and shorter learning curves could be obtained.

Mechanical Ridge Tier

To respond to the labor constraint in constructing tied ridges, the IITA/SAFGRAD Agronomy Program designed a prototype mechanical ridge tier (MRT) (Figure 1) for animal traction (Wright and Rodriguez, 1985).[6] With FSU and IITA/SAFGRAD collaboration, the MRT was field tested as part of Burkina's 1985 national farming systems program (Nagy, *et al.*, 1986). Yield levels compare favorably between ridges constructed with animal traction but tied manually and those ridges made with the MRT. When the two pass method is used (first ridging and then using the MRT) the MRT substantially reduces the labor requirements from an average of 75 man hours/ha for the manual tying of animal traction ridges to 20 man hours/ha. The MRT operation requires only 2 to 3 additional hours above ridging alone when ridging and tying with the MRT are done simultaneously (one pass). Donkeys must be strong and healthy for the one pass method. Oxen, which are mainly available on the frontier, clearly have an advantage and can easily do both operations simultaneously. LP farm models indicate that while available labor constrains the tying of ridges manually to 1.1ha (Table 3, column 2), the MRT can tie 3.2ha when using the one-pass method (Table 3, column 4) and is highly profitable. The profitability is further increased with the addition of fertilizer (Table 4) although hectarage under tied ridges decreases to 0.9 for manual tying and to 3.0 with the MRT because labor is required for fertilizer application. Budget analysis also indicated the profitability of the MRT under various prices and good/bad year weather scenarios (Nagy, *et al.*, 1986).

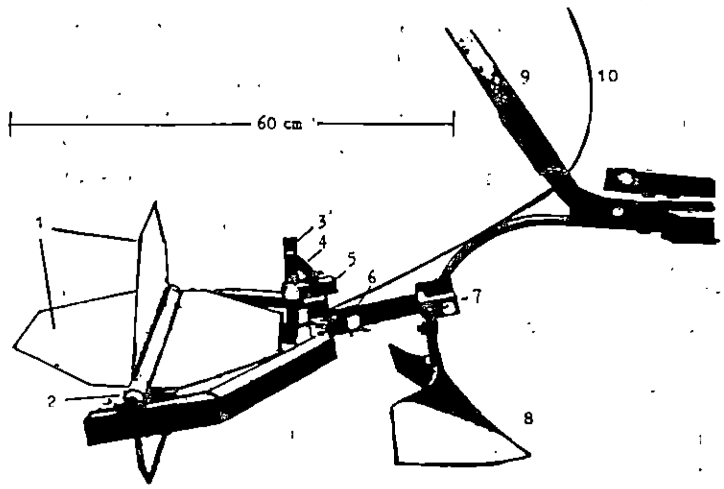
Information from farmer questionnaires and field staff indicated that the major problem with the MRT was its awkwardness. However, most farmers were able to operate the MRT fairly efficiently after 15 to 30 minutes in the field. Several engineering features require redesigning but the overall consensus of the field trials is that the MRT or a machine similar to the MRT can be used at present not only as a labor-saving device but also as a yield-increasing technology.

Herbicides

Herbicides could be used to decrease the labor constraint in the peak-labor-demand planting/weeding period (Spencer, 1985). At present, acquiring herbicides in the WASAT is difficult and little research has been done to tailor herbicides to WASAT conditions. Broad leaf and slender leaf plants as well as various trees are grown in association in the same field and these are sensitive to different herbicides.

Economic analysis in northern Nigeria (Ogungbile, 1980) suggests that weeding, either by animal traction or manually, is more profitable than herbicides. Herbicides will find an increasing role in the WASAT only when cropping intensities are increased to the point where they require more intensive weeding (Norman, 1982) and when further research allows herbicides to be more effectively used on cereal-legume associations.

[6] The MRT is attached to an animal drawn cultivator with one large middle sweep. The MRT is essentially a paddle wheel (45cm in diameter) with four paddles, one scraping the ground, building up earth until it is tripped by the operator every 1½ to 2 meters to create the tie in the furrow between the two ridges.



1. Shovels
2. Axel Bearing (Pipe)
3. Latch Lever
4. Rubber Band (Inner Tube Strip)
5. Latch Adjuster (for correct angle and to compensate for wear in bearings, shovels and latch).
6. Shovel angle Adjusting Bolt
7. Coupler
8. 30 cm Ridger that allows soil to flow over the top.
9. Handles of "houe Manga" (FAO donkey weeder)
10. Bicycle cable to Brake Lever

Figure 1 The IITA/SAFGRAD mechanical ridge tier (donkey version).

Table 4 Whole farm modeling analysis of a tied ridging-fertilization technology combination with donkey traction, Central Plateau, Burkina Faso.

		Tied-ridging technology[1]		
	Traditional management (donkey)	Tied by hand	Tied with machine	
Variable			Two passes	One pass
	hectares			
Total area cultivated	5.5	5.6	5.7	5.6
Maize				
Traditional	.20			
With tied ridges		.20	.15	.15
Red sorghum				
Traditional	.60			
With tied ridges		.60	.68	.60
White sorghum				
Traditional	.80	.70		
With tied ridges		.10	.80	.95
Millet				
Traditional	3.18	3.15	3.18	1.88
With tied ridges			.05	1.27
Peanuts	.76	.86	.79	.71
	Total cereals production	kgs		
Per household	2103	2604	2970	3354
Per resident[2]	150	186	212	240
Net farm income[3]		000's FCFA		
Per household	215.3	253.2	273.2	296.4
Per worker[4]	30.8	36.2	39.0	42.3

Source: Nagy et al., 1985.

[1] Based on application of 100 kg/ha 14-23-15 fertilizer at planting and 50 kg/ha urea four weeks after planting (20 man hours/ha labor requirement for each application). Labor times of 75 man hours/ha for tying of the ridges by hand, 20 man hours/ha to machine tie with two passes, and 2 man hours/ha to machine tie in one pass. Yield estimates in kgs/ha for traditional practices and the technological interventions of fertilization and tied ridges in combination are as follows: maize – not fertilized (1090 to 1730), red sorghum (672 to 1236), white sorghum (472 to 913) and millet (320 to 660). 1985 fertilizer and grain prices were used.

[2] Based on 14 residents/household.

[3] Annualized cost of 4,400 FCFA for machine subtracted in columns 3 and 4.

[4] Based on 7 active workers/household.

Improved Varietal Research

Few improved varieties of food crops are used by farmers in the WASAT. Significant yield increases for varietal improvement from on-station research have been observed but a large yield gap between on-station and on-farm yields exists, especially for the staple crops of sorghum and millet. Experimental results suggest that the cereal yield gap is less for local than for improved cultivars (Matlon, 1985).[7] Yields from FSU on-farm trials in

[7] Analysis of the five management factors of plowing, tied ridges, fertilization timing, planting arrangement and weeding timing indicated that the major determinants of the yield gap between the experiment station and farmers' fields were plowing and tied ridges (Maton, 1985). Also, the major problems observed in the on-farm trials with the elite cultivars are drought and heat stress related, leading to poor seeding establishment and poor flowering and grain filling ability. Spittlebug problems have occurred on the new sorghum variety of Framida (Ohm et al., 1985b) and striga continues to be a problem with most new sorghum varieties.

Burkina for improved maize, red and white sorghum, and cowpeas rarely exceeded the yields of local varieties under traditional management treatments (FSU Annual Reports).

Analysis by ICRISAT of sorghum and millet cultivars indicate that the on-station selection procedures under a high management environment (high fertility, tillage and water management) have resulted in elite cultivars being more management responsive than local varieties but at the same time inferior at lower management levels (Matlon, 1985). This suggests that breeding objectives should include screening and selection procedures that can provide cultivars which also exploit moderate management levels and that there is a need to hasten the process of variety evaluation onto on-farm trials (Matlon, 1985). With the current selection procedures, the full impact from varietal development will only be felt in the WASAT when farmers utilize a higher degree of improved management practices – practices such as an MRT-fertilizer combination – which would not take place until the intermediate run. Also, even if changes occur in the present breeding objectives, leading to the development of new varieties able to exploit moderate management levels, these varieties will only be available in the intermediate run (five to ten years).

Crop Associations

Experiment station studies of different crop associations have received increased attention in the WASAT over the past 15 years (Fussell and Serafini, 1985). Significant aggregate biological yields from intensifying cereal-cowpea associations have been obtained in research station trials (Fussell and Serafini, 1985; Muleba, 1985). Increased legume densities, however, are normally accompanied by serious insect infestation problems requiring pesticide spraying. The role to be played by biological nitrogen fixation is unclear and would require either sole cropping of legumes in rotation with cereals or a substantially higher legume density in associations.[8]

On-farm researcher-managed trials indicate that the most limiting factors in the performance of cereal-cowpea association intensification are soil moisture and fertility (Ohm, *et al.*, 1985a). Under favourable conditions of moisture and fertility, it is profitable to increase cowpea density, but under less favorable conditions, the present practice of the farmers seems to be more dependable and profitable (Sawadogo, *et al.*, 1985). Under improved management (tied ridges, fertilizer and pesticides), cowpea densities somewhat higher than those currently used by farmers are likely to be economically viable (Sawadogo, *et al.*, 1985). Although returns to labor can be greater under intensification, farmers do cite lower cereal yields and increased labor demands as the prime reasons for not intensifying (Matlon, 1983).

Limited research has been carried out on cropping associations involving trees in the WASAT. Alley cropping – food cropos growing in the alley formed by rows of leguminous shrubs or trees – could form the basis for changing traditional shifting cultivation practices (Kang, *et al.*, 1984). Alley cropping does possess many advantages such as providing mulch, firewood, biologically fixed nitrogen, animal feed and erosion control. However, the

[8] The role that biological nitrogen fixation has played in obtaining the increased aggregate yields in cereal-legume associations in the WASAT is yet to be determined (Fussell and Serifini, 1985). Studies have shown, however, that under WASAT water stress and mineral deficiency conditions, some legumes may contribute to nitrogen losses (Pieri, 1985).

method is very management-intensive and has not been thoroughly researched in the WASAT. Some intensification of cereal and legume crops can take place in the intermediate run once the physical environment is improved, but signfiicant crop intensification, alley cropping, and biological nitrogen fixation would contribute their greatest potential in the long run after farmers first increased their cereals production.

Policy Implications and Future Avenues for Research and Extension

From the information presented in Table 1, this report proposes that the overall sequence of technology intervention for the WASAT is: 1) technologies that improve the agronomic environment, i.e., water retention and soil fertility improvement (with appropriate policy and institutional support this technology combination can be immediately implemented; 2) the use, when they become available, of improved varieties that can exploit moderate input levels (if varieties are developed for the moderate input levels recommended in 1) above, this technology is expected to be available for farmer adoption in the next five to ten years); and 3) more intensive livestock/cereal systems in the better agricultural areas and a shift back to extensive grazing and forestry in the more marginal agricultural regions. (There are many types of technologies for those intensive livestock/cereal/cash crop systems that can now be productively studied on the experiment station and in on-farm trials so that these systems can be available to farmers after the next decade).

The first priority of the agricultural policy, research and extension community in the WASAT is to develop technologies to increase the yields of the cereal-based farming systems which dominate the area. The present focus should be on alleviating the low soil fertility/low soil water retention constraints. Complex fertilizers, the water retention methods of tied ridges, diguettes and dikes, and the labor-saving technologies of animal traction and the mechanical ridge tier are already available for extension in much of the region.

Tied ridging, chemical fertilizer, and animal traction, however, have all been potentially available to farmers in the WASAT for more than two decades. Yet there has been little adoption by WASAT food crop producers of any of these three innovations. This is because there was little economic incentive to adopt these technologies prior to the 1960s because food consumption needs were being met. Moreover, there was little export demand for sorghum and millet. Hence, there was little demand for new cereal technologies. However, with increased population, recent droughts and the deterioration of the soil quality in the higher population regions during the intervening years, the demand for new cereal technology has substantially increased.

Credit, fertilizer, and animal traction non-availability and lack of information have all been cited as reasons for the low level of farmer adoption in the WASAT. From our perspective the principal reason for the failure to adopt these individual components is that the economic impact of each of the three components has not been sufficiently high by itself. Fertilizer utilization is too risky in poor rainfall years without some simultaneous method to increase the availability of water at the critical times of plant development. Tied ridges by themselves do not resolve the low soil fertility problem. Family labor availability constrains the amount of tied ridging construction. It appears from the on-farm trials and the whole-farm modelling results that all three technologies (including the MRT) would need to be introduced together before economic incentive and risk levels were adequate for technology adoption. Introducing the technologies together would alleviate the soil fertility, soil water and labor constraints and provide high economic incentives at levels of risk that would be attractive to farmers. However, as previously discussed, farmers adopt technologies sequentially and not as a package.

An option is to wait for the research community to develop new technologies that will, individually, provide a sufficient economic incentive at a level of risk that is attractive to farmers. The review of the constraints to cereal production and the review of the available and future technologies for the WASAT (Table 1) point out that such technologies will not be available in the short run and will probably not be available in the intermediate run (10-15 years). The pressing problems of the WASAT require more immediate solutions. Another option is to develop support programs that will enable farmers to sequentially adopt the available technologies en route to total package adoption.

Implementation of a support program to increase the present cereal production in the WASAT would include: a) credit programs for the cash outlays required by farmers for fertilizer and animal traction; b) farm management information, especially on efficient utilization of animal traction and fertilizer, from the extension service; c) development of the input and product markets.

To facilitate new-technology introduction, some of the potential types of research and extension institutional support programs are mentioned below.

Priorities for Extension and Local Governments

The highest priorities for extension and local government agencies involve focusing on the soil fertility/water retention technologies of manual tied ridging, diguettes and dikes, complex fertilizer, animal traction and the mechanical ridge tier. These technologies should be put forward on demonstration fields, (using local farmer participation were appropriate) individually and as package.

There is a role for local government agencies in the construction and maintenance of large dikes and barriers to regulate the speed of rainfall runoff at the village level. Within each region, individual households would either construct tied ridges and/or diguettes – whichever is the most appropriate for the area. Where diguettes are used, assistance from local government agenices may be required for correct contour placement.

A critical role will be that of the extension agencies which will need to ensure that the appropriate pre-conditions exist for animal traction adoption. The pre-conditions of shorter learning curves for both the farmer and draft animals and higher utilization rates can be facilitated by animal traction programs. Extension agencies could be involved in training farmers (technical operation and animal maintenance) and in the training of draft animals until a draft animal market develops. Shortening the learning curve will itself increase utilization rates which can be further increased by an appropriate complement of implements including the mechanical ridge tier.

Priorities for On-Farm Testing

The prototype IITA mechanical ridge tier requires further modifications at the engineering level to reduce its weight and awkwardness and increase its adaptability for hook-up with a wide range of cultivator/plow equipment (Nagy, *et al.*, 1986). Other possibilities include an automatic tripping device and even new design concepts, which need to be rigorously field tested with farmer participation. As modifications and new design concepts are developed, they must be made available to the extension system and local manufacturers and provisions made for information feedback to the on-farm testing agencies. The mechanical ridge tier is an implement that can be made locally and every attempt by the local extension agencies to provide prototype copies to local manufacturers should be undertaken. Locally-made mechanical ridge tiers enable location-specific adaptations arising from a local manufacturer/farmer interchange.

Priorities also include further on-farm testing of diguettes and of modifications of diguettes and barriers. Further on-farm testing across the WASAT of raw and acidulated rock phosphate from all the major rock phosphate deposits in the WASAT is required to evaluate the agronomic and economic feasibility of this technology.

Priorities for Experimental Research Stations

On-station, crop improvement programs require a change in the present emphasis on screening and selection under high management conditions – management conditions much higher than can be provided by WASAT farmers in the intermediate run. Thus, crop improvement programs in the WASAT should concentrate on developing varieties that show stability over time and exhibit a response curve that exploits moderate management levels. Selection must be focused on resistance to important pests and diseases as well as production superiority under varying levels of soil productivity and available soil moisture – all of which are factors contributing to production stability. this change in crop development goals requires new screening and selection procedures and an increased inter-disciplinary effort between on-station and on-farm research.

The designing of labor-saving devices for fertilizer application, planting and other field operations should be further studied for both manual and animal traction farmers where applicable. Research on water retention methods other than tied ridges or diguettes for those areas where these two technologies are not effective is required.

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49 Experience en matiere d'essais dans les champs des paysans: Etude de cas au Mali

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Introduction

Créé en 1977, le projet SAFGRAD se fixait pour objectif l'accroissement du volume total des recherches axées sur les céréales et les légumineuses à un moment où les pays situés dans les zones semi-arides d'Afrique étaient confrontés aux dures problêmes de la sècheresse qui chaque jour s'imposait en maître absolu de la nature. C'est donc dire qu'il est né à une période où il était le plus attendu dans la mesure où il devrait aboutir à la création de programmes des Responsables de Production Agricole Accélérée (RPAA) chargés de promouvoir le développement des cultures vivrières dans les pays membres.

C'est ainsi que dès sa création, le programme RPAA/MALI a eu pour mission d'assurer la liaison entre la recherche et la vulgarisation par l'introduction au sein des Organismes de Développement Rural (ODR) des innovations techniques avec pour objectif majeur, la maximisation des rendements dans les systèmes de production agricole des paysans.

Le Mali, pays enclavé s'étend sur environ 1,24 millions de km^2, soit 4,2% de la superficie totale du continent africain. Ce pays à moitié aride, est situé entre les latitudes 10° à 26°N et les longitudes 12°0 à 4°15E. Le Mali est borné au nord par la Mauritanie et le Sahara algérien, à l'est et au sud-est par le Niger, au sud par le Burkina-Faso et la Côte d'Ivoire, au sud-ouest par la Guinée et à l'ouest par le Sénégal.

Agriculture et Elevage au Mali

Au Mali, l'agriculture est l'occupation principale de 90% de la population. Les mils, le sorgho, Digitaria exilis et l'arachide sont les principales cultures vivrières produites par 80% de la population active qui emploient les techniques traditionnelles d'une agriculture d'autoconsommation. Vient ensuite le riz, dont la moitié est cultivée dans le delta central du Niger; d'autres régions rizicoles sont la vallée du Sénégal, la vallée du Niger de Bamako à Ségou et de Gao à Ansongo ainsi que la région de Sikasso dans le sud.

Les meilleures alluvions de la vallée du Niger sont cultivées en maïs dont la moitié de la production provient de Sikasso, en arachide et en cultures maraîchères. Sont aussi cultivés les fruits, surtout les mangues, afin de mieux satisfaire aux besoins alimentaires des populations notamment urbaines.

Le coton et l'arachide, deux importantes cultures commerciales sont destinés aux industries nationales et à l'exportation. Le Coton est surtout cultivé dans la région de Sikasso, qui fournit la moitié de la production; le reste vient des régions de Ségou, Mopti, Koulikoro et du district de Bamako. La culture de l'arachide est surtout concentrée dans l'ouest, les régions de Kayes, de Koulikoro et le district de Bamako produisant deux-tiers de la récolte. Le thé, la canne à sucre, le riz et le tabac ont été introduits respectivement dans les régions de Sikasso, Ségou, Koulikoro et le district de Bamako. La gomme, Juglans cinerea et le Kapok sont cultivés dans la région sahélienne. Ké-Macina, dans le delta central du Niger avec ses sols fertiles se prête aux cultures industrielles irriguées telles que le riz, le coton, le thé et la canne à sucre.

Dans plus de la moitié du pays, le milieu aride ne permet que l'élevage itinérant, par exemple le nomadisme (Touaregs) et la transhumance (Peulhs) dans le Sahel et les régions sahariennes. L'élevage sédentaire se pratique essentiellement dans le sud du Mali.

La pisciculture date de l'antiquité. L'activité est surtout concentrée dans la vallée du Niger et son delta central ainsi que dans les lacs entourés par la boucle du fleuve. Les centres principaux de pisciculture sont Ségou, Mopti et Gao.

L'économie de ce pays est fondée sur l'agriculture et dépend par conséquent de la pluviométrie. Celle-ci étant insuffisante sur plus de la moitié du pays, l'agriculture est concentrée dans le centre, à l'ouest, au sud et au sud-ouest du pays constitués respectivement par des sols ferrugineux tropicaux, ferrugineux tropicaux et hydromorphes, ferrugineux tropicaux lessivés de type hydromorphe et ferrugineux tropicaux hydromorphes peu humifères.

Classification Climatique · Approches du Troll (1965) cohemé Franguin (1967)

La classification climatique est un indice utile des conditions écologiques, du potentiel agricole et de l'environnement en général d'un pays. La

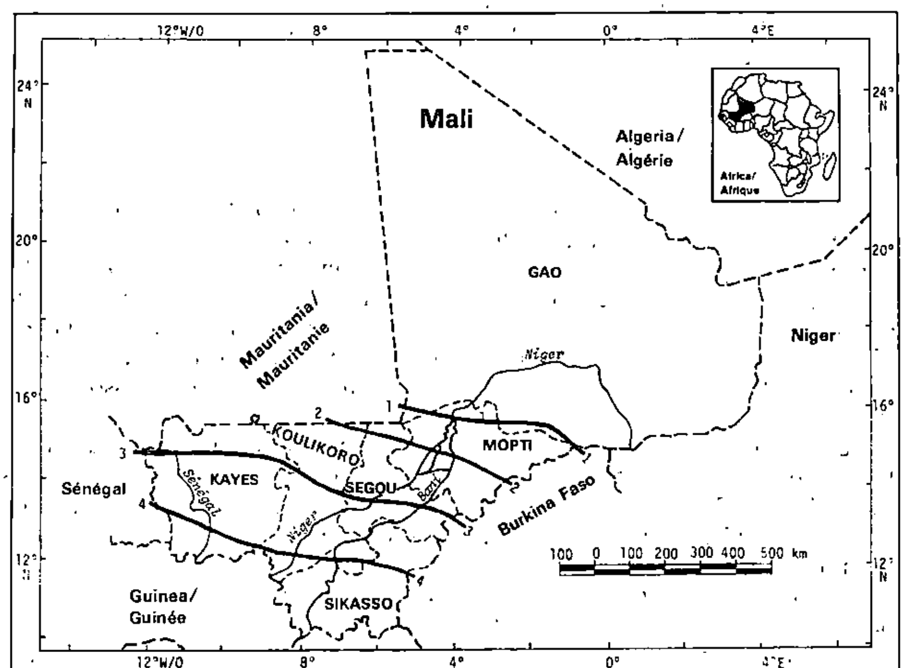

Figure 1 Nombre de mois humides (d'après la méthode de Troll) au Mali.

délimitation des différentes zones climatiques est indispensable au transfert des techniques adaptées de l'aménagement du sol, de l'eau et des cultures. Les systèmes de classification reposant sur les données relatives à la précipitation de l'ETP présentent un avantage puisque ces paramètres permettent d'évaluer le milieu hydrique. Cet aspect est d'autant plus important au Mali où le manque d'eau pose une contrainte fondamentale.

La classification d'après Troll est fondée sur le nombre de mois humides dans l'année plutôt que la précipitation annuelle. Est considéré comme un mois humide, celui où la précipitation moyenne est supérieure à l'ETP moyenne. Nous disposons des données sur la pluviométrie et l'évaporation potentielle mensuelles relatives à 80 stations du Mali (Virmani et al 1980). D'après Troll, les zones ayant 2 à 4,5 mois humides dans l'année sont désignées savanes arbustives ou zones tropicales sèches et les zones de 4-5-7 mois humides sont désignées savanes sèches ou zones tropicales semi-arides à saisons sèche et humide. La zone semi désertique ou aride est celle n'ayant que 1 à 2 mois humides. Les mois humides ont été déterminés d'après le système de Troll pour toutes les stations au Mali. A part Gao et la moitié Nord de la région de Mopti, le Mali sera classé dans les zones tropicales sèches (Fig. 1). La moitié nord de Mopti (1-2 mois humides) est situé dans la zone semi désertique. Toute la région de Gao sauf une bande étroite autour de Hombori se situe dans la zone désertique.

Situation pluviométrique de 1978 à 1985

Le tableau 2 nous indique l'évolution de la pluviométrie dans les zones agricoles du Mali de 1978 à 1985. L'analyse du même tableau nous montre que dans les zones sud et sud ouest aux isohyètes 600-100mm et 900-1200mm les pluviométries moyennes effectivement enregistrées vont de 797mm en 1978) 556mm en 1985, une nette décroissance progressive de la pluviométrie au taux de 30% en moyenne à partir de l'année 1978. Ce phénomène a été observé dans le sud et sud-ouest comme la CMDT, l'OHV et l'ODIPAC. Quant au nord l'OMM, et l'ODIK l'insuffisance pluviometrique n'est pas un phénomène inattendu mais avec la période de sècheresse la diminution du peu d'eau qui tombait à beaucoup attiré l'attention des populations. La decroissance pluviométrique d'une année à l'autre va de 67% à 55% avec une moyenne de 58%. Dans le nord la trop grande baisse de la pluviométrie risque de rendre impossble la production vivrière dans cette zone (Tableau 2).

Tableau 1 Duree de la periode de croissance sur des sols a capacite de retention en eau variable pour les stations indiquees au Mali

Station	Capacité de rétention en eau du sol (mm)	Durée de la période de croissance (sem.)
Sikasso	60	27
	250	32
Bamako-ville	150	24
	200	24
Ségou	120	17
	190	19
Kayes	120	19
	190	21
Mopti	100	14
	270	16

Tableau 2 Situation pluviométrie des operations de developpement rural de 1978 à 1985

	Opérations de Developpement Rural				
	ODIPAC	OHV	OMM	ODIK	CMDT
Moyenne pluriannelle Théorique	600-1000	700-1000	400-600	300-600	900-1200
Moyenne annuelle (semis-récolte) 1978-1979	797	683	381	686	–
Moyenne annuelle (semis-récolte) 1979-1980	420	740	397	418	787
Moyenne annuelle (semis-récolte) 1980-1981	506	537	416	229	516
Moyenne annuelle (semis-récolte) 1981-1982	527	663	364	307	613
Moyenne annuelle (semis-récolte) 1982-1983	354	396	229	289	441
Moyenne annuelle (semis-récolte) 1983-1984	424	398	367	–	458
Moyenne annuelle (semis-récolte) 1984-1985	424	491	275	290	584
Moyenne annuelle (semis-récolte) 1985-1986	556	569	310	285	667
Moyenne pluriannuelle enregistrée	501	560	342	358	581

Activites du programme RPAA/Mali de 1978 à 1985

Dans le cadre de la mission qui lui a été assignée, definie par l'article No. 2 de la convention d'agrément signée entre le Gouvernement de la Republique du Mali et l'OUA/CSTR, le programme RPAA réalise dépuis sa création en 1978 des tests de prévulgarisation axés sur des thèmes variés en reponse aux besoins réels des paysans en matière de resultats de recherches.

Compte tenu du fait que les grandes actions entreprises par les autorités politiques et administratives pour l'accession à l'autosuffisance alimentaire du pays ont toujours été victimes des caprices du climat et que les productions vivrières demeuraient extrêmement vulnérables aux accidents climatiques, il devenait de plus en plus obligatoire pour une dynamisation des structures de production du secteur rural, de mettre à la disposition des paysans des moyens d'intervention rapides et appropriés.

Devant cette situation combien dramatique, la recherche se devrait d'agir en mettant à la disposition du programme RPAA des paquets de technologies destinés à améliorer les systèmes de production des exploitations agricoles paysannes qui constituent de nos jours les cellules motrices de notre développement économique.

L'objectif vise par les tests paysans ou la prevulgarisation

Au Mali les zones rurales sont entièrement encadrées par les services de vulgarisation. Tout le progrès de la masse rurale dépend à 100% des services de développement. La politique de l'encadrement du paysan est de lui apporter tous les nécessaires pour promouvoir la production agricole afin d'améliorer ces conditions socio-économiques. Pour répondre à ce souci, les services d'encadrement doivent lui:

- apprendre les connaissances de base en matière de production agricole;
- apporte les moyens de production les plus utiles lui permettant de réaliser ses travaux le plus facilement possible.
- apprendre comment il doit profiter au maximum de l'utilisation de ces moyens mis à sa disposition;
- apporter enfin toutes autres innovations techniques visant à accroitre la production agricole ou à améliorer ses conditions socio-économiques.

D'une manière générale, toutes les innovations que les développeurs vulgarisent ou enseignent au paysan viennent de la recherche. Si la recherche doit travailler pour promouvoir la production agricole au niveau de la masse rurale, tous ses résultats doivent être destinés à cette masse rurale qui pour les chercheurs constitue le milieu réel et la finalité de tout programme de recherche. Toutes techniques ou tous résultats de recherche confirmés sont ainsi cédés totalement aux ODR intéréssées pour leur vulgarisation.

La recherche faisant passer chez les utilisateurs (les paysans) ses technologies mises au point, pourra contribuer valablement à l'augmentation de la production agricole dans le milieu rural d'une part et d'autre part aller de l'avant dans ses programmes car les technologies déjà adaptées ne feront plus l'objet de recherche.

Enfin l'introduction dans le milieu rural des techniques nouvelles notamment les variétés améliorées de céréales et de légumineuses, des pratiques culturales compatibles avec les systèmes de production des exploitations agricoles paysannes par le biais des services de vulgarisation, constitue pour le programme RPAA/MALI un atout sérieux dans la réussite du pays d'accéder à l'autosuffisance alimentaire.

Ainsi après avoir défini les priorités des Opérations de Développement Rural (ODR) en matiére de recherche, les travaux de recherche sont exécutés par les chercheurs à l'issue desquels des résultats sont obtenus. Ceux-ci ne constituent pas une fin en soi. Ils doivent passer dans le milieu paysan pour une confirmation et cette confirmation se fait à l'aide des tests de prévulgarisation qui sont une application directe des résultats des stations de recherche chez le paysan avant la vulgarisation proprement dite. Ce travail de prévulgarisation est effectué par l'entremise des services de vulgarisation.

De 1978 à 1985 au total 1181 tests de prévulvarisation ont été implantés au niveau des Organismes de Développement Rural (ODR) chargés de promouvoir le développement socio-économique des paysans. Les programmes ont porté sur:

I. l'introduction de nouvelles variétés de céréales et de légumineuses;
II. la fertlisation des sols (le phosphate Naturel de Tilemsi)
III. des techniques culturales comme l'association de cultures à savoir:
- la culture de relais maïs-niébé
- l'association maïs-mil.

Ces programmes ont été mis sur place dans le cadre des efforts du Mali dans la lutte contre la sècheresse pour l'accession à l'autosuffisance alimentaire.

L'introduction de nouvelles variétés de céréales et de legumineuses

Avec la persistance et l'accentuation de la sécheresse de ces dernières années marquant dans tout son ensemble l'agriculture malienne parce que ne permettant plus aux variétés locales de boucler leur cycle végétatif, les services de vulgarisation oeuvrant pour la promotion des cultures vivrières ont demandé à la recherche de mettre à la disposition des agriculteurs des variétés améliorées précoces et demi-précoces de céréales (mil maïs sorgho) et de légumineuses à graines (niébé) en tenant compte des spécificités climatiques de chaque zone.

C'est donc en réponse à ce besoin et dans le but de juguler le fléau qu'est la sècheresse par la rélance des productions vivrières se trouvant de nos jours à leur niveau le plus bas, que le programme RPAA/MALI a centré ses efforts sur l'introduction de nouvelles variétés de céréales et de légumineuses dans le milieu paysan.

Ainsi le RPAA/MALI a mis en comparaison dans une même zone écologique et dans les mêmes conditions de culture, des variétés locales de céréales ou de légumineuses avec de nouvelles introductions de mêmes espèces à cycles aparentés.

Les tests de comparaison ont été réalisés sur le terrain avec tout le paquet technologique donnant les conditions améliorées de culture de céréales et de légumineuses à savoir: le labour, semis en ligne, utilisation des engrais, sarclage regulier, traitement phytosanitaire etc. . .

Les fumures minérales utilisées pour la culture des différentes espèces ont été celles préconisées par les services de vulgarisation et supposées répondre au pouvoir d'achat des paysans. Il s'agit de:

Pour le sorgho et le mil

- 100 kg/ha de complexe coton ou de phosphate d'ammoniaque au semis
- 50 kg/ha d'urée au 30é jour après le semis.

Pour le Maïs

- 100 kg/ha de complexe coton ou de phosphate d'ammoniaque au semis.
- 100 kg/ha d'urée en doses fractionnées de 25 kg/ha aux 30è et 50è jours après semis.

Pour le Niébé

- 65 kg/ha de super simple au semis.

Tests variétaux de céréales: (sorgho, mil et maïs)

Les tableaux 3 et 4 nous illustrent les écarts entre le rendement potentiel et ceux obtenus dans la milieu rural pour chaque variété testée. Dans le nord les écarts vont de 5% à 60% y compris les variétés locales et dans le sud-ouest 21 à 48% pour le sorgho.

Quant aux mils, dans le nord les écarts vont de 33 à 79% y compris les variétés locales et dans le sud ouest 62 à 64%. Ces pourcentages d'une manière générale représentent la reduction dans le potentiel productif des variétés dans nos conditions de sècheresse. Cette sècheresse est mise en évidence dans le tableau 2 pur une reduction progressive de la pluviometrie zonale de 1978 à 1985.

Dans cette période le facteur climat a été le facteur le plus déterminant du rendement des cultures. Les années concernées étaient caractérisées par une installation tardive des pluies (25 Juin au 15 juillet), les manques de pluies en milieu de saison de 10 à 15 jours et des arrêts précoces inattendus des pluies en fin de saison ne permettant pas aux différentes cultures de bien boucler leur cycle végétatif.

En effet le facteur sècheresse a anéanti tous les autres facteurs pouvant influer positivement sur les cultures à savoir: les labours, semis à temps l'apport des engrais, la physique des sols etc... .

Dans ces conditions de sècheresse évoquées nous avons essayé d'apporter à la recherche dans le cadre du "feedback" les variétés qui ont présenté de grandes défaillances pour les améliorer davantage et proposer à la vulgarisation celles qui se sont montrées rélativement performantes.

En effet pour répondre à l'objectif visé dans le cadre de l'introduction variétale en milieu paysan, les réponses aux questions suivantes étaient recherchées:

- Quelle serait la variété la plus productive sans apport d'engrais ou avec une faible dose d'engrais?
- Compte tenu des rendements obtenus en milieu rural et des prix actuels de l'engrais, l'émploi d'une faible dose d'engrais sur la culture céréalière aura t-il un intérêt économique immédiat?
- Enfin si les nouvelles variétés de céréales se revélaient être plus productives, seraient-elles adoptées par le consommateur Malien?

En ce qui concerne les deux permières questions, aucune des variétés introduites de sorgho ou de petit mil n'a dépassé, en moyenne de rendement, les variétés locales que ce soit avec ou sans engrais.

Au contraire, les variétés locales ont réagi aussi bien, sinon mieux que les variétés introduites à la faible dose d'engrais (100 kg/ha de phosphate d'ammoniàque et 50 kg/ha d'urée), avec un surplus de rendement de 139 kg/ha en moyenne. Les raisons évoquées pour expliquer la faible performance des variétés introduites ont été les suivantes:

- le faible taux de germination constaté dans les conditions de culture du paysan (faible adaptabilité)
- le manque de vigueur des jeunes plants (faible adaptabilité)
- la grande sensibilité au striga
- la moisissure des grains et les attaques d'oiseaux en cas de maturation précoce.

Tableau 3 Resultats des tests de comparaison varietale de sorgho de 1978 à 1985. Rendements moyens annuels en kg/ha des variétés testees avec fumures minrales vulgarisees.

Zones	Variétés	Années 1978	1979	1983	1984	1985	moyennes Pluriannuelle	rendement potentiel	% réduction
Nord	CE 99	2371	1397	–	–	–	1884	2500	25
	CE 90	1564	–	523	936	1008	1008	2500	60
	Locales	1449	1045	406	734	1099	947	1000	5
Sud-Ouest	SB 722/1	–	–	1324	1230	–	1277	1800	29
	SB 722/93	–	–	–	885	1422	1154	2000	42
	SH2D2	–	–	914	1156	–	1035	2000	38
	E 35-1	1667	1152	–	–	–	1410	2000	30
	Locales	1371	7155	807	913	1082	1186	1500	21

Tableau 4 Resultats des tests de comparaison varietale de mils de 1978-1984 rendements moyens annuels en kg/ha des variétés testees avec fumures minerales vulgarisees.

Zones	Variétés	Années				moyenne Pluriannuelle	rendement potentiel	% reduction
		1978	1983	1984	1985			
Nord	M2D2	426	408	444	–	426	2000	79
	NKK	526	510	540	770	584	2500	61
	3/4 NK	–	637	267	–	452	1500	70
	Locales	632	682	611	774	667	1000	33
Sud-Ouest	M12	847	750	710	–	769	2000	62
	M9	920	855	930	–	902	2500	64
	Locales	1002	682	611	–	765	2000	62

Ainsi certaines variétés de sorgho telles que les SB et de petit mils telle que le 3/4 NKK ont été retournées à la recherche pour ample amélioration. Les variétés de sorgho CE 90, CE 99 ont été proposées à la vulgarisation pour leur précocité (80-90 jours) d'autres sont en voie de vulgarisation comme les variétés CSM 219, Malisor 84-1, CSM 63 ont été proposées à la vulgarisation et celles en voies de vulgarisation sont les CSM 388, Malisor 84-3, Malisor 84-7.

En ce qui concerne les mils, M2D2 et NKK ont été proposées à la vulgarisation comme précoces (80-90 jours), celles en voie de vulgarisation sont l'IBV 8001, HKP, Torognou de Ningari etc. . . Pour les variétés intermédiaires M9 et M12 ont été proposées à la vulgarisation.

Pour ce qui concerne les tests maïs (tableau 5), contrairement aux sorgho et mil les variétés introduites se sont montrées suppérieures aux variétés locales. Les écarts entre le rendement potentiel et ceux obtenus en milieu paysan vont de 9% à 61% en moyenne qui sont inférieurs à ceux obtenus avec le sorgho et le mil. Toutes ces variétés de cycle intermédiaire (100-110 jours) ont été testées dans les zones sud et sud-ouest du Mali à pluviométrie 800-1200mm. L'obtention des résultats rélativement bons nous a aménés à faire des tests de dégustation qui ont d'ailleurs prouvé la très bonne adaptabilité des maïs Tiémantié de Zamblara, l'IRAT Z-81 et Txpeno-1 au "to", couscous et à la boullie couramment consommés par les maliens.

Ainsi le Tiémantié de Zamblara et le Tuxpeno-1 ont été proposés à la vulgarisation avec d'autres variétés précoces pour les zones Nord du Mali telles que le SAFITA-2, Pool 16, Zanguereni, Kogoni B etc. . .

L'IRAT Z-81 n'a pas pu être proposé à la vulgarisation malgré ses bons résultats pour son caractère hybride. Le problème qui se pose à la culture à grande échelle de cet hybride est celui de l'approvisionnement en semences d'IRAT-Z-81, si l'ont sait que celles-ci doivent être renouvelées tous les ans.

Tests varietaux de leguminneuses (Niébé)

Dans les conditions actuelles de pluviométrie très souvent insuffisante pour permettre aux cultures (notamment celles constituant la base de l'alimentation des populations) de boucler convenablement leur cycle de développement végétatif; des tests de culture pure de niébé ont été conduits dans certaines opérations de développement en vue d'apporter un appoint à l'alimentation aussi bien humaine qu'animale. Durant ces deux campagnes les tests de niébé ont porté surtout sur la variété TN 88-63 à laquelle sont venus s'ajouter le Gorom-Gorom, la KN-1, et la TCX 32-36.

Les résultats obtenus pendant ces deux dernières années ont montré la supériorité des variétés introduites par rapport aux variétés locales de niébé (tableau 6).

D'une manière générale, les variétés améliorées de niébé TN 88-63, Gorom Gorom, KN1 et TVX 32-36 ont, partout où elles ont été comparées aux variétés locales répondu aux attentes des paysans. Cependant, il convient de signaler que ces résultats obtenus, bien que satisfaisants aux yeux des paysans nous paraissent de loin inférieurs aux potentiels productifs des variétés mises en comparaison. La diminution constatées des rendements aurait pu être évitée si les tests n'avaient pas été victimes des:

- semis tardifs suite à l'installation tardive des pluies,
- travaux d'entretien (sarclages) mal ou non effectués;
- traitements phytosanitaires insuffisants ou parfois absents;

Tableau 5 _ Resultats des tests comparaison varietale de maïs de 1978 à 1985. Rendements moyens en kg/ha des variétés testees avec fumures minerales vulgarisees.

Zones	Variétés	Années						moyennes pluriannelles	rendement potentiel	% reduction
		1978	1980	1981	1983	1984	1985			
Sud	Tiématié	2273	2242	1320	1570	1805	–	2219	4000	45
	IRAT-81	–	3276	4268	–	–	–	3772	5000	25
et Sud-ouest	Tuxpéno-1	–	–	–	1661	1580	1420	1554	4000	61
	Locales,	1902	–	3262	1284	1414	1230	1818	2000	9

Tableau 6 Recapitulatif des rendements kg/ha et densite/ha des tests varietaux de niébé. Variétés locales comparees a TN 88-63, GOROM-GOROM, KN-1 et TVX 32-36

ODR	1984				pluviométrie semis-récolte (mm)	1985						Pluviométrie semis-récolte (mm)
	Rendements kg/ha		Densité/ha			Rendements kg/ha			Densité/ha			
	V1	V2	V1	V2		V1	V2	V3	V1	V2	V3	
OMM												
Moyennes	169	518	41 933	54 150		54	301	–	46 587	47 309	–	
t(0,05)		HS		S	307		HS			NS		296
CV %		6		11			3			42		
ODIK												
Moyennes	346	933	38 792	48 038	244	464	862	720	38 321	37156	44261	246
t(0,05)		HS					HS		S			
f(0,05)												
CV %		10					37	14				
OHV												
Moyennes		Néant				520	796	–	40 571	39 139	–	481
t(0,05)							S			NS		
CV %							11			56	–	
DRAS												
Moyennes		Néant				161	777	–	42 914	43 251		404
t(0,05)							HS			NS		
CV %							7			–		
ODIP-AC												
Moyennes		Néant				593	567	623	38 886	40 881	41805	546
f(0,05 variétés)							NS			NS		
CV %							33			7		

NB.: V1 = variétés locales
V2 = TN 88-63
HS = Hautement significative; S = Significative; NS = Non significative

V1 = Variétés locales; V2 = TN 8863; KN-1
V3 = Gorom-Gorom, TVX 32-36

- mauvaises répartitions des pluies dans le temps avec des ruptures de 10 jours parfois aux périodes critiques de la végétation.

Les variétés ci-dessus citées après ces deux années de tests seront proposées à la vulgarisation.

Ainsi, à partir de l'expérience des tests de prévulgarisation conduits dans la presque totalité des régions agricoles du pays par l'entremise des Opérations de Développement Rural force est de reconnaître que les rendements des variétés locales aussi bien que ceux des variétés amélioreés de céréales ont été beaucoup affectés par la sècheresse. Les ruptures des pluies aux différents stades phénologiques critiques des cultures ont été à l'origine des rendements catastrophiques enregistrés dans les champs.

Par le fait du manque des pluies, les opérations culturales ne sont plus effectuées correctement. Les semis sont faits sur des terrains non labourés, ayant subi au plus un grattage. Dans le pire des cas, la mort ou la faiblesse des animaux de trait par manque de nourriture exclut toute intervention des matériels modernes. La dégradation de plus en plus accentuée des sols de culture a conduit à la destabilisation de leurs structures déjà profondement touchées par de nombreuses années de monoculture de mil de sorgho ou de maïs etc. . .

A cela il faut ajouter que l'insécurité de la culture sèche née des caprices du climat a augmenté le pessimisme des paysans créant chez ces derniers une certaine reticence aux engrais minéraux. L'incidence de ces différentes contraintes au développement des productions vivrières a eu pour conséquence la chute vertigineuse des rendements des cultures.

De 1978 à 1984, dans le sud ouest les moyennes de rendements ont passé de 1371 kg/ha à 913 kg/ha avec une moyenne pluriannuelle de 1186 kg/ha pour les variétés locales de sorgho utilisées dans les tests de comparaison variétale avec des variétés améliorées de la même espèce chez lesquelles les moyennes ont oscillé entre 1667 kg/ha et 1152 kg/ha avec une moyenne pluriannuelle de 1410 kg/ha en dépit de la fumure minérale apportée. Ces chiffres comme on le voit sont largement inférieurs aux 2000-2500 kg/ha (tableau 3) representant le rendement potentiel de ces variétés dans les conditions de pluviométrie normale. Durant la même période, les rendements des variétés locales et améliorées de mil ont passé de 632 kg/ha à 611 kg/ha avec une MPA de 667 kg/ha pour les locales 408 à 444 kg/ha avec une MAP de 426 kg/ha pour l'améliorée M2D2 dans le nord (tableau 4). On a pu également constater qu'avec l'absence de pluies, les variétés améliorées de mil étaient fortement attaquées soit par les chenilles au stade 3 à 4 feuilles, soit par les insectes (cantharides) et les oiseaux granivores en cas de maturation précoce.

Comme dans le cas précédent, on voit encore qu'aucune des variétés ne s'est rapprochée de son optimum de production. Ceci a été observé dans toutes les zones où la culture du mil est prédominante et où la moyenne pluviométrique annuelle est de beaucoup inférieure à 800mm.

S'agissant des résultats des tests de maïs (tableau 5) ceux ci ont passé de 3262 kg/ha à 1230 kg/ha pour les variétés locales et de 3205 kg/ha á 1570 kg/ha pour les variétés améliorées avec des moyennes pluriannuelles de 1818 kg/ha et 2219 kg/ha. Ceci explique que de nos jours les variétés améliorées de maïs se soient subtituées aux variétés locales des paysans par le faide leur productivité et de leur rélative tolérance à la sècheresse. Ces résultats bien que quelque peu satisfaisants aux yeux des paysans, ne permettent pas de fonder un espoir quelconque quant à l'accession à l'autosuffisance alimentaire de nos populations.

Dans la mesure où dans la quasi totalité des exploitations agricoles paysannes les cultures ne reçoivent que très peu ou pas de fumure organique par le fait de la décimation du cheptel et encore moins de la fumure minérale devenue onéreuse pour les paysans, on est en droit de s'attendre à des résultats beaucoup plus catastrophiques dans les campagnes.

La chute exacerbée des productions en dépit des multiples efforts consentis ajoutée aux pertes de récoltes consécutives à la mauvaise conservation des denrées, éloignet chaque jour les pays sahéliens de l'objectif ambitieux de l'autosuffisance alimentaire et de ce fait crée la dépendance de ces pays à l'aide alimentaire.

C'est ainsi qu'en 1983, le déficit vivrier du Mali, alors estimé à 180000 tonnes par le plan quinquennal de 1981-1985, a brusquement double, atteignant les 330000 tonnes.

Quant au niébé, en dépit des irrégularités observées tout au long des dernières années, nous osons espérer que la culture du niébé trouvera la place de choix qu'il convient de lui accorder dans l'agriculture malienne, à un moment où celle-ci est confrontée aux durs problèmes de la sècheresse. Les variétés de niébé de bonne qualité nutritive commencent à faire déjà leur place dans l'alimentation des populations.

La fertilisation des sols: (phosphate naturel de Tilemsi)

La plupart des sols cultivés au Mali sont pauvres en phosphore. Compte tenu du coût actuel des engrais chimiques importés et suite aux nombreuses études sur l'emploi direct du phosphate naturel de Tilemsi sur les cultures vivrières, le SAFGRAD/MALI, dans le cadre de son programme de prévulgarisation, a essayé le phosphate naturel de Tilemsi auprès des paysans dans les conditions rurales en collaboration avec les opérations de développement.

Ces tests sur le phosphate naturel de Tilemsi avaient pour but:

a) de suivre l'effet résiduel d'une dose de 300 kg/ha de phosphate naturel de Tilemsi apportée en 1ère année selon que la rotation soit légumineuse-céréale ou céréale-céréale.
b) d'améliorer la richesse de nos sols en phosphore et
c) de diminuer l'importation des engrais chimiques au prix de revient trop éléve pour nos paysans.

D'une manière générale, nous avons observé un effet maximum du PNT en deuxième année de culture et des minimums en première et troixième années; la première étant supérieure à la troisième. Les pourcentages d'augmentations sont les suivants: 33 à 37% pour le sorgho, 43% pour le petit mil et 26 à 28% pour l'arachide avec un taux d'intérêt d'investissement de 128% supérieur au seuil de 100% recommandé par la FAO pour qu'une technique nouvelle soit acceptée par les paysans du tiers monde.

1) En tant que précédent cultural, l'arachide a permis une augmentation de rendement des céréales de 125 kg/ha indépendamment du phosphate de Tilemsi.
2) L'apport d'urée est resté économiquement sans effet appréciable.
3) Quant au phosphate naturel de Tilemsi, les résultats obtenus sont encourageants;

- dans la rotation céréale-céréale, il a permis un intérêt d'investissement sur deux ans de 157%
- dans la rotation arachide-céréale, l'intérêt d'investissement sur deux ans a été de 128%.

L'association de cultures

Les principaux arguments avancés pour justifier l'association de cultures sont les suivants:

1. la tradition;
2. le besoin de maximiser le rapport du facteur le plus limitant,
3. le besoin de sécurité;
4. l'effet bénéfique des légumineuses sur d'autres cultures (Norman, 1977) et
5. évaluer le potentiel de production et le comprtement des deux cultures exploitées en association.

Tests culture de relais maïs-niebe

De 1978 à 1984, implantés dans le sud et le sud-ouest du Mali CMDT, OHV et ODIPAC) ces tests avaient pour but de maximiser l'exploitation du terrain par la production d'une culture principale de maïs et d'une culture secondaire de niébé pour l'alimentation humaine à partir des graines et animale à partir des fanes.

Le LER (Land Equivalent Ratio ou Rapport de Surface Equivalente) est un élément d'appréciation pour la culture de relais, il s'avère donc utile de dégager avec ce calcul le gain du paysan en pratiquant ce système de culture.

Ainsi les analyses ont montré des moyennes d'augmentation de rendement de 27 à 64% en faveur du système de relais avec la production de maïs grain+niébé gousses et 22% d'augmentation avec maïs grains+niébé fane. D'autre part des avantages économiques moyens du système relais de l'ordre de 68 6750F/CFA à 80 000F/CFA sur la culture pure du maïs et 185 650F/CFA à 202 350F/CFA sur la culture pure du niébé ont été obtenus.

A partir de ces résultats escomptés des années 1982, 1983 et 1984 du système de culture de relais maïs-niébé, cette pratique a été proposée à la vulgarisation au niveau de l'OHV, l'ODIPAC et la CMDT.

Tests d'association maïs-mil: campagne 1984 et 1985

Ces tests avaient pour but de: comparer une pratique de culture associée en lignes alternées à celle en poquets alternés couramment observée chez les paysans de la région de Sikasso. La technique de cultures associées en interlignes est dite améliorée et celle en interpoquets est dite traditionnelle.

Dans la pratique de l'alternance des lignes de maïs et de mil les rendements moyens obtenus ont été de 409 kg/ha pour le maïs et 597 kg/ha pour le mil avec un pourcentage d'augmentation de 54% en 1984, 2201 kg/ha pour le maïs et 494 kg/ha pour le mil avec un pourcentage d'augmentation de 49% en 1985.

Dans la pratique de l'interpoquets (pratique du paysan) nous avons obtenu 1059 kg/ha pour le maïs et 751 kg/ha pourle mil avec un pourcentage d'augmentation de 48% en 1984. En 1985, les moyennes de 1587 kg/ha et 504 respectivement pour le maïs et le mil avec un pourcentage d'augmentation de 26% ont été obtenus.

En 1985, les moyennes de 1587 kg/ha et 504 respectivement pour le maïs et le mil avec un pourcentage d'augmentation de 26% ont été obtenus.

Au vu de ces résultats de deuxième année de test sur les deux pratiques et de l'avis des paysans, l'avantage constaté dans la méthode des interlignes nous amène à conclure que cette pratique dite améliorée peut être conseillée aux paysans de la CMDT au détriment de celle dite traditionnelle.

Conclusion

Malgré les actions multiples et diversifiées entreprises pour atténuer, voire enrayer le danger que represente la sècheresse, les conditions déxistence des peuples saheliens sont toujours des plus médiocres. La famine, la malnutrition et tant d'autres sont des maux avec lesquels les populations sahéliennes sont appélées à vivre tant que des solutions appropriées ne leur seront pas trouvées. La rareté et l'insuffisance des précipitations atmosphériques, la rupture des grands équilibres écologiques, la hausse spéctaculaire des facteurs de production agricole etc . . . étouffent chaque jour toute tentative d'une relance de la production. Les récoltes au lieu de se maintenir baissent d'année en année sous la menace persistante de la sècherésse en dépit de l'introduction de variétés améliorées précoces. Dans cette situation difficile et désesperée; la question reste posée à savoir: quelles stratégies adopter?

Suggestions

(1) Pour endiguer les conséquences désastreuses de la sècheresse auxquelles les pays du sahel sont particulièrement confrontés depuis plusieurs années, une aide alimentaire accrue soutenue par une aide au développement demeure indispensable.

Davantage de ressources doivent être consacrées aux recherches sur les systèmes d'agriculture pluviale en mettant sur pied des programmes destinés aux petites exploitations agricoles paysannes entrainant des moyens peu coûteux sur le plan de la production. La diversification des cultures et l'extension des aménagements hydro-agricoles doivent être envisagées. Si des efforts ne sont pas conjugués dans ce sens pour freiner les sècheresses généralisées qui ne cessent de se repeter compromettant dangereusement les récoltes, l'accession à l'autosuffisance alimentaire de la sous-région restera un vain mot.

(2) La sècheresse qui sévit depuis plus d'une décénnie dans les pays du sahel a eu pour conséquence au Mali la chute vertigineuse des rendements des cultures suite à l'arrivée tardive et à l'arrêt précoce des pluies les plus souvent mal reparties dans l'espace et dans le temps. Les sols pour la plupart dénudés, privés de leur flore ont du coup perdu toutes leurs caractéristiques de bonnes terres de cultures. Les efforts entrepris pour atténuer, voir enrayer à long terme le danger, sont restés vains en l'absence d'une pluviométrie satisfaisante.

Les variétés améliorees intermédaires et précoces introduites par la Recherche agronomique par le biais des tests de prévulgarisation

SAFGRAD n'ont pas suffi pour lever le défit à cause des adversités d'un climat devenu de plus en plus capricieux.

Devant cette situation combien catastrophique, il devient impérieux de rechercher des solutions appropriées susceptibles de réhausser le niveau de production des exploitations agricoles paysannes et prenant en considération le pouvoir d'achat de leur exploitant.

(3) Dans les pays tropicaux semi-arides tels que le Mali, la pluviosité variable et aléatoire pendant la période végétative à une incidence sur le potentiel agricole d'autant plus que la demande atmosphérique reste toujours élevée. Il faut donc bien comprendre ce rapport étroit entre le climat et les systèmes de production agricole; en particulier la variation des rendements qu'entraînent les aléas du climat. Une description et une analyse adéquate des paramètres climatiques s'avèrent donc nécessaires à l'application des connaissances agrométéorologiques en vue d'une amélioration des systèmes de production agricole.

Ainsi la nécessité de recherches sur les céréales et les légumineuses en Afrique doivent porter sur l'amélioration des plantes en vue de les adapter à l'évolution des systèmes de cultures, de leur donner une qualité nutritive meilleure et de leur conferer une resistance aux ravageurs à la sècheresse, aux maladies, au striga et aux autres parasites etc. . .

Enfin la détermination des systèmes de production grâce auxquels les cultivateurs pratiquant une culture de subsistance pourront tirer des céréales et les legumineuses un maximum d'aliments constitue un objectif à atteindre immédiatement.

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50 The 1985 On-Farm Test Results of Sorghum Varieties: Comparison of 535 with local varieties over two years and 165 sites.

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General Background

The SAFGRAD project began in 1977 to promote increased reearch on food crops in the semi-arid tropics of Africa. Known as well by Joint Project 31 of the Scientific, Technical, and Research Commission of the Organization of African Unity, this project was designed as the continuation of Joint Project 26 of the O.A.U. which ended in 1975. SAFGRAD activities are coordinated from the project headquarters in Ouagadougou and covering 25 member countries, with nearly 300 million habitants, SAFGRAD provides funds to IITA and ICRISAT for research programs of regional importance on food crops of the semi-arid zone. SAFGRAD fosters improved communications among food crop researchers in the region by sponsoring group visits to member country research programs and by organizing conferences and seminars on topics of high regional importance for maize, cowpea, sorghum and millet research. Finally, SAFGRAD has financed the activities of Accelerated Crop Production Officers (ACPO) in five member countries to expedite the transfer of research results to farmers fields for increased food crop production.

SAFGRAD in Cameroon

SAFGRAD activities in Cameroon began in 1979 with the arrival of the ACPO, Owen Gwathmey. He and his counterpart, Mr. Martin Fobasso, conducted station level and farmer level trials on food crops in Northern Cameroon through the 1983 crop season. Mr. Fobasso went to the U.S. for long term training and Mr. Gwathmey was replaced as ACPO by Mr. Jerry Johnson in early 1984. Mr. Johnson and his counterpart have conducted on-farm trials on maize, sorghum, peanuts and cowpeas during the 1984 and 1985 crop seasons with the able assistance of two technicians; Mr. Albert Diak and Mr. Joseph Samaki.

Since 1979 when Mr. Gwathmey began varietal trials on research stations for the major food crops in Northern Cameroon the physiognomy of food crop-research in the North has changed. The addition of a cowpea entomologist, a sorghum breeder, a peanut breeder and a cereal agronomist, all of whom work primarily on research stations on their respective crops, have enabled the ACPO program to direct its efforts towards the increasingly important task of liaison between food crop research and extension in Northern Cameroon. Consequently the major portion of the ACPO program from 1983 to 1985 has been to conduct on-farm trials in the five northern-most regions of the SODECOTON extension zone that extends from the Nigerian border to the Tchadian border and from Sorawel to Mora.

The Goals of On-farm Testing in Cameroon

- To increase food crop production in the semi-arid zone of Northern Cameroon by the adoption and utilization of agronomy research results in farmers fields.
- To establish an on-farm testing network within agronomy research capable of conducting on-farm tests within the means and institutional capacities of the research and extension organizations in Northern Cameroon.

Objectives of On-farm Testing in Cameroon

1. To provide new and improved extension themes to extension agencies in Northern Cameroon that have been proven (by on-farm test results) to significantly increase yields of maize, sorghum, millet, peanuts or cowpeas and are otherwise acceptable to, and adoptable by, local farmers.
2. To provide quantitative and qualitative feedback to on-station research to assist them in fixing research priorities for their respective crops that reflect the experience gained from on-farm tests conducted under local conditions with local farmers.
3. To contribute to on-farm testing methodology as the appropriate research methodology for certain research questions that are more efficiently investigated in farmers fields than on research stations.
4. To train field extension agents to conduct on-farm tests and to help extension administrators to formulate new extension themes from on-farm test results.
5. To demonstrate new techniques and improved varieties to farmers and to collaborate with farmers to ensure local acceptability and adaptability of improved technology.

On-farm Testing Methodology

On-farm testing as practiced in Northern Cameroon is a link between research and extension for increasing food crop production. By definition, on-farm testing would be useless if either research or extension were weak or non-existent. A weak food crop research program would mean a shortage of viable test themes to be tested by farmers. Weak or non-existent extension capacity would imply no need to develop new and improved extension themes because they could not be extended to farmers. On-farm testing is not a substitute for either a strong station research program or an effective extension agency – it is a complementary activity that makes both parent structures stronger and more effective. Consequently agronomy research and SODECOTON cooperate with one another and local farmers to implement the on-farm testing program in Northern Cameroon. There is a healthy division of responsibilities that have evolved over time as the most harmonious and effective manner to conduct on-farm tests.

In short, the following responsibilities are assumed by the different parties:

IRA

Home for the pre-extension section, is responsible for financial and technical administration. Practically, IRA provides the annual work plan with the people and materials necessary to execute the program.

Sodecoton

Provides time and resources of over 300 field agents to supervise the implementation of the on-farm tests. They also provide input into the choice of on-farm themes and formulate new extension themes from on-farm test results. They provide those inputs which are part of their production inputs; fertilizer and insecticide.

Farmer

Provides seed of his local variety for varietal tests. He and his family perform the physical labor for conducting the test and provides animal traction (if available) for plowing and weeding. The farmer provides the land for the test and keeps all of the harvest. Over 60 hectares were farmed under on-farm test conditions by local farmers in 1985.

On-farm Testing in the Year – Field Observations

Work Plan

SAFGRAD submits preliminary results for the preceding year and a proposal for new test themes to a joint meeting of IRA and SODECOTON in early January. New themes are based on the results and experience of the previous year and on individual contributions of each collaborating station researcher. The number of tests are a function of expected budgets from IRA and USAID. A full report of test results and a revised proposal is then proposed to the agronomy research meetings under the Farming Systems, Cereals, and Grain Legume Research Programs.

Choice of Extension Agent, Farmer and Test Field

SODECOTON divides the number of tests for a given theme among their five regions and 23 sectors in such a way that each sector has approximately the same number of tests. Each sector head then chooses the field agent best qualified to conduct each test. IRA researchers intervene at this point, usually the end of April or beginning of May, to group the field agents from three or four sectors together to explain the implementation of each test and to distribute the necessary inputs (seeds, fertilizer, raingauges). The field agents are instructed how to choose a collaborating farmer and how to choose an appropriate field. They are furnished a simple but detailed set of instructions outlining each operation that must be undertaken in the year.

May-June

Agents choose farmers and fields and supervise soil preparation and seeding as a function of rainfall and exigencies of the test instructions. This usually includes measuring out the test borders and treatment limits and marking them with wooden stakes or rocks. The farmer then clears the field of crop residues and the agent installs the raingauge beside the test site. From this point on, the agent or his literate designee must go to the test site each day that it rains to record daily precipitation. When it rains the field is plowed and seeded by the farmer under the supervision of the agent as a function of the field plan provided in the test instructions and the agent records requested dates and seeding observations.

June-July: The First Field Tour

The first tour of test sites by the SAFGRAD team occurs between the 10th of June and mid July. Each agent, farmer, and field is visited and observations are made concerning the choice of the field and status of soil preparation and seeding. Early season problems are discussed and solved as much as possible. Most frequently, this first tour finds some agents who haven't begun test preparations and if the collaborating farmer has been chosen, the field is not staked out. Sometimes an inappropriate test site has been chosen and a new field or farmer must be sought out. For those sites that have been correctly seeded, a common problem is low plant density. Sometimes the field was not planted according to test specifications. Most often, however, either inadequate soil moisture or early season insects are the cause of low densities. In 1985 systematic reseeding seven days after seeding was part of test instructions. Each test is furnished with enough seed for more than one complete reseeding but agents often permit farmers to exceed the recomended number of seeds per hill and additional seed must be provided by the SAFGRAD team at the time of the first tour. A single soil sample is taken by the SAFGRAD team at each site. Probably the most important aspect of the first tour is meeting the tour schedule thereby demonstrating IRA's intention to seriously and professionally follow the on-farm test. Simple presence of the SAFGRAD team in the villages and fields provides inspiration to the agent and farmer and often makes the difference between a successful test conducted according to test specifications and a headache during the entire season.

A Note on Visits to On-Farm Tests

The organization of test site visits by the SAFGRAD team is an example of on-farm testing methodology that has become vastly more efficient over time. With a small number of test sites the SAFGRAD team could spend one day in one or two fields so the time required to find the agent and farmer and go to the field was not a constraint. In 1984 there were five or six test sites in each sector that usually had to be visited in one day in order to make a complete tour of all test sites in three weeks to one month. After the first tour of 1984 it became obvious that the on-farm test visit schedule could only be adhered to if the agents (and farmers) were informed in advance of the date of the visit. With agents awaiting the arrival of the team visit at their houses, then and only then, five to six test sites could be visited in one day. The schedule of a complete tour to the twenty-three sectors is fixed one to two weeks in advance and radio messages with visit dates are sent to each of the five regions who, in turn, inform the sector heads who, in turn, inform their zone heads and field agents. This system worked remarkably well in 1984 and again in 1985 when, with ten to eleven tests per sector, informing agents in advance was indispensable. The system depends, however, on reliable vehicles and healthy team members. Nothing is more discouraging to an agent and farmer than waiting all day for a field visit that never materializes. The cooperation of the entire SODECOTON organization is essential to the field visit system though the field agents are directly concerned. The sector head or his designee usually accompany the SAFGRAD team on field visits. The field agent informs the farmer of the impending visit and this usually instigates a flurry of work on the test site so it will be presentable to the visitors. Team visits including the sector head of extension are invaluable opportunities to SAFGRAD team members to better understand the production potential and constraints in the sector. The success of this system depends on people cooperating together. There are unlimited possibilities for either research or extension personnel to accuse the other of failing to fulfill responsibilities. Fortunately, this has not occurred to date. The farmers of Northern Cameroon have been the most open and cooperative element in the on-farm testing system.

The Second Tour: End of July to Beginning of September

For research this is the most important and arduous task. Most important due to the amount of information to be collected: plant density counts, measurements of exact area of each treatment, recording operations performed by treatment, verification of adherence to test instructions, agronomic observations on insects, diseases and soil, and recording rainfall from the beginning of the season. Often the conditions are wet, roads impassable, farmers busy with other farming activities, and field agents fully occupied by their cotton production program. Since the last visit the farmer will have seeded (if not already done), reseeded, weeded and applied fertilizer. The pre-season enthusiasm and "belles paroles" will have been distilled down to the need for hard work and close supervision. Although the test instructions are made as clear and simple as possible, some agents fail to follow them or fail to visit the test site regulalry so animals graze in the test, fields become weedy, fertilizer is not applied correctly, or reseeding is too late and plant densities are low. From experience, most of the success of the test depends upon successful implementation of the test at the beginning of the season. Something like, "He who starts well finishes well".

Finally the instructions for harvest are distributed during the second tour and are discussed in the field with the agent and the farmer. Normally the ten central rows of a twenty row treatment that is fifty meters long are harvested for yield calculations. Many field agents take the area to be harvested.

Inaccessibility of sites or missed rendezvous are the major problems of this tour. Working on a schedule, it is difficult to return to a missed site until all twenty-three sectors have been visited.

Distribution of Sacks

In 1984 the harvest sacks (16-20 per site) were supplied by SODECOTON and distributed primarily by the region heads. The sacks were late arriving to many test sites and cowpea yields were probably reduced. In 1985 SAFGRAD furnished the sacks and distributed them to the sector heads who were to distribute them to the individual agents at the end of September and beginning of October. Many sector heads were on vacation, therefore some agents didn't receive the sacks in time for harvest. Some delayed harvest awaiting the sacks. Recuperating the sacks at the end of the season is difficult.

Harvest

The harvest season is broken into two parts with cowpeas, maize and peanuts being harvested during September and October. Sorghum harvest extends from the end of October to the beginning of December. In 1985 a tour of all cowpea and peanut sites occurred in October. Farmers harvested the ten central rows of each treatment under agent supervision and the produce is put into sacks and ticketted by the agent. These sacks are then transported to the farmer's house or the SODECOTON storage facility to dry. Cowpea and peanut harvests were weighed (in the pod) and a sample from each treatment was taken for post-harvest analyses. The cowpea research section in Maroua used these samples to calculate threshing percentage (thus grain yields), the amount of pod damage due to *Maruca*, the number of holes in 100 grains due to bruchids, and the 100 grain weight. The same section selected twelve on-farm test sites for post-harvest on the amount of loss due to bruchids under farmer conditions. The peanut research section in Maroua furnished sample bags and tickets so that each variety (4) would be sampled by harvesting one row at random and putting all pods (even empty or damaged) into the sample bag. They measured loss of weight to correct harvest data from these samples as well as making estimates of millipede damage and shelling percentage by variety. These post-harvest studies would have been impossible without cooperation of these two sections as the SAFGRAD team was fully occupied with the harvest of the on-farm sorghum tests. The peanut samples also revealed the fact that the new, early-maturing peanut varieties were harvested almost 30 days after maturity as farmers and agents awaited the maturity of the later maturing 28-206.

Sorghum Harvest

This operation in 1985 was the most arduous organizational task that SAFGRAD has undertaken. Some 163 test sites were visited at least two times each between the 31st of October and the 12th of December. The harvest schedule was based on three teams in the field per day. The first visit served to obtain panicle weights for the ten central rows of each treatment, collect test material, and give instructions for threshing. The second visit to the same site came two or three days later and was intended to obtain grain weights and collect all test data. After weighing, a questionnaire was answered by the farmer and his family concerning their reaction to the themes tested in their field during the season. Certain questions concerning consumer preference of varieties or constraints to adoption of a given technology resulted in valuable information. Other questions were too vague or conditional to be of much value. The overriding observation of the SAFGRAD team was that they didn't know how useful the answers would be for a report but that they, individually, learned an enormous amount from local farmers by the structured and repeated questions. Some sites, perhaps as much as 25% had to be visited several times as this harvest period coincided wth the vacation period of most of the field agents. An unusually high number of sites were lost due to the absence of field agents during the critical harvest and weighing period. Approaching harvest in the middle of September we estimated a success rate of over 95% but by the time all the data was in and critically inspected the successful test percentage had dropped to 83%. In addition to sacks arriving late at some sites, and field agents on vacation, there were some sites where farmers mixed all treatments together.

During September and part of October the SODECOTON field agents were occupied with the payment of cotton rebates from last year's harvest and then went on vacation so the farmer was deprived of close supervision. It is especially painful to lose an on-farm test result at the last minute due to harvest discrepancies. Foraging animals were again a problem in some sites at the end of the season as this harvest and weighing period coincides with the *Muskwari* or *Babouri* sorghum season when the farmer's labor demands are high and field surveillance almost impossible.

Vehicle and personnel demands are also high at IRA during harvest season, SAFGRAD was able to meet this demanding schedule only because DMS/USAID in Maroua loaned them a vehicle and a driver during the month of November.

Finally, small samples of grain from each treatment were taken to the lab after grain weighing to perform the following post-harvest analyses by the SAFGRAD team:

1. Correction of yield data for moisture. Each sample weighed in, dried in oven for 24 hours at 65°C, and weighed out.
2. Conversion of kg/ha to liters/ha from three 100ml subsamples.
3. Estimation of grain mold by scoring 0-4.
4. 1000 grain weight for each sample (new in 1985).

Analyses

In October SAFGRAD received an IBM/PC which has expanded, enormously, their analytic capacity.

Orientation of the 1985 On-Farm Test Program

Sorghum

The surprising results of the new sorghum variety S35 in the adverse conditions of 1984 had to be confirmed in another year. As the program indicates S35 was to be tested in 1985 under conditions less favorable to its

Table Review of 1984 Test Results. Summary Table of 1984 On-Farm Sorghum Variety Results (kg/ha)

Region	Ave S35	Ave Local	Ave 38-3	Differ. S35-Local	No. Tests
Diamare	796	564	439	232*	20
Mora Mokolo	1319	629	739	690**	22
Kaele	1373	941	–	432**	20
Mayo Danay	1830	802	–	1028**	17
Mayo Louti	1529	630	–	899**	9
All Regions	1333	719	–	614	88

LSD.01=238 kg/ha

1) S35 is significantly superior to the local variety in each of the five regions with an average superiority of 614 kg/ha.
2) Neither E35-1 nor 38-3 are statistically different in yield than the local variety in any of the five regions.

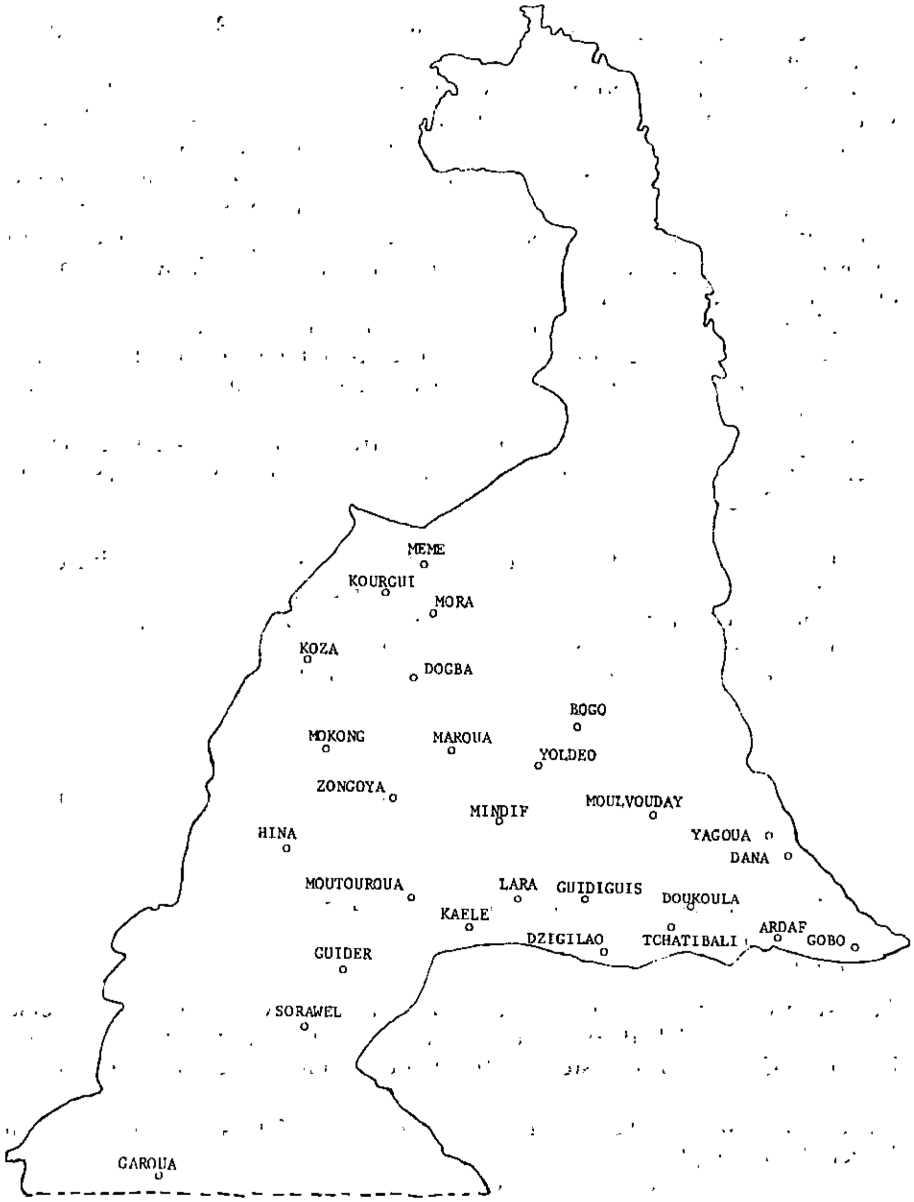


Figure 1 Map of Northern Cameroon showing the test sites.

performance to see if it would still compare favorably to the local varieties. It was put in 48 early-seeded varietal tests and 23 varietal in fields infested with *Striga*. It was also used as the unique variety in two different soil preparation tests to measure its response to plowing, direct seeding, dry scarification and tied ridges. Believing that S35 would probably be confirmed by 1985 results and would be proposed to extension in 1986 it was felt that the 1985 tests should fill out the elements of an extension recommendation package. Consequently a more complicated test with twelve treatments was designed to examine the response to urea by S35. 1985 was essential to the Seed Multiplication agency to multiply sufficient seed of S35 for extension.

1985 On-Farm Test Program for Soprghum Varieties

Theme	Number of tests distributed	Number of test results	% of success
Early-Seeded Sorghum	48	42	88%
Sorghum in Striga Infested Fields	23	21	91%
Late-Seeded Sorghum	23	16	70%

1985 Results of 48 On-Farm Early Seeded Sorghum Varietal Tests

Test Site Distribution

Two tests were distributed to each of twenty-three SODECOTON sectors and one to the Catholic mission in Mokolo and one to the Pilot Project in Mindif. Test materials were distributed between the 11th and 18th of April.

Varieties: S35, Local, and S34

Test area: 1/4 hectare divided into three equal plots

Test conditions:
Preceding Crop: Cotton
Seeding Period: 15 May to 15 June
Plant Density: 62,500 plants/ha (80cm × 40cm × 2 plants)
Reseeding: 7 days after seeding (d.a.s.)
Weeding, Thinning and Urea Application (100 kg/ha): 21 d.a.s.

Test statistics and linear correlations with grain yield

Variable	*Mean*	*Stand.dev.*	*r*	*Prob.*
Date of seeding	14/6	10 days	NS	
Density pl/ha	42811	11355	.169	.065
Days to reseeding	11	8	NS	
Days to weeding	23	6	NS	
Days to urea application	32	13	NS	
Rainfall 1-90 d.a.s.	504	117	−.284	.001
Soil pH (30 cm)	5.65	.88	NS	
% sand (>.5mm)	27.2	11.6	NS	

Analyses of variance:

Grain yield kg/ha
Variety S35 – 1866 kg/ha
Variety Local – 1721 kg/ha
Variety S34 – 1666 kg/ha

S35 vs Local – 145 kg/ha NS (prob. = .129) CV = 25%
Local vs S34 – 55 kg/ha NS
S35 vs S34 – 200 kg/ha S (prob. = .037)

Plant density (at approx. 30 d.a.s.)
Variety S35 – 40,838 pl/ha
Variety Local 43,882 pl/ha CV = 17%
Variety S34 – 44,185 pl/ha

S35 vs Local NS (prob. = .06) difference = 3034 pl/ha
Local vs S34 – NS
S35 vs S34 – S (prob. = .039) difference = 3337 pl/ha

Conclusions

1) There was no significant difference in yield between S35 and the local varieties in the early-seeded tests. This suggests that S35 can be seeded early as well as late and not risk yielding less than the local varieties.
2) Perhaps most surprising in this test are yields of S35 that are 40% higher than average yields in 1984 when average plant densities were 25% lower in 1985 than 1984. Given similar planting instructions, generally good climate conditions, and the best S35 seed available, it is uncertain why the plant densities were so low in 1985.
3) Grain mold scores were worse for S35 than for the local varieties in this test but there were no cases of serious grain mold even though farmers waiting an average of 32 days after maturity of S35 before harvesting. The abrupt end to the rainy season may not have favored grain mold development in 1985 despite the early dates of seeding. No farmers complained about grain mold on S35 during harvest season interviews.

1985 Results of 16 On-Farm Late Seeded Sorghum Varietal Tests

Test site distribution: This test was distributed to each of the twenty-three SODECOTON sectors, but only sixteen viable results were obtained.

Varieties: S35, Local, S36, and S20.

Test area: 1/4 hectare divided into four equal plots.

Test conditions: Same as for early-seeded sorghum except:

Seeding period: 15 June to 15 July.

Test statistics and linear correlations with grain yield

Variable	*Mean*	*Stand.dev.*	*r*	*Prob.*
Date of seeding	28/6	10.6	–.25	.042
Density pl/ha	45667	9269	.28	.024
Days to reseeding	6.9	6.5	.381	.001
DAys to weeding	22.1	6.4	.271	.030
Days to urea application	27.6	8.7	.267	.032
Rainfall 1-90 d.a.s.	515	129	NS	
Soil pH (30 cm)	5.9	.97	NS	
% sand (>.5mm)	25.6	7.3	NS	

Variety means on certain characteristics

	Days seeding to harvest	Grain weight per panicle	Grain to panicle ratio	Grain mold score
Variety S35	111	38g	.76	1.125
Variety Local	114	33g	.72	.188
Variety S36	115	27g	.70	1.688
Variety S20	117	22g	.54	1.063

Analyses of variance:

Grain yield kg/ha
Variety S35 – 1416 kg/ha
Variety Local – 1156 kg/ha CV = 49%
Variety S36 – 805 kg/ha
Variety S20 – 601 kg/ha

Variety S35 vs Local – difference = 260 kg/ha NS
Variety Local vs S36 – difference = 350 kg/ha S (prob. = .046)
Variety S36 vs S20 – difference = NS

Plant density plants/ha
Variety S35 – 46816 pl/ha
Variety Local – 48119 pl/ha CV = 14%
Variety S36 – 44361 pl/ha
Variety S20 – 43371 pl/ha

No significant difference

General Observations and Conclusions

1) Note a general negative correlation between date of seeding and yield indicating that, unlike 1984, this seeding period was too late for high yields. The test mean yield is considerably lower than the mean for the early seeded tests though means of plant densities were higher for the late seeded tests. *Striga* appeared more serious on these late seeded tests than the early seeded tests. By interview, farmers were asked about the absence or presence of *Striga* in each variety and these results show that the 27 plots reported to have been infested with *Striga* had a mean yield of 843 kg/ha by comparison to 1279 kg/ha for those plots reported free of *Striga*. Grain mold scores for both S35 and the local varieties were lower for these late seeded tests. A glance at the mean seeding dates for the "early-seeded" tests (14/6) and the "late-seeded" tests (28/6) show that only two weeks separated the two mean seeding dates thus "early" and "late" became highly relative; due primarily to dry climatic conditions at the end of May and beginning of June in 1985.
2) The two new varieties S36 and S20, chosen for their earliness and short stature, failed to demonstrate any redeeming characteristics. Due to their low yields, the questions of preferable plant height for local farmers had no meaning.

1985 Results of 21 On-Farm Sorghum Varietal Test in Fields Infested with Striga

Test Site Distribution

One test in each of the twenty-three sectors of SODECOTON. Twenty-one viable results were obtained.

Varieties: S35, Local, S34, and 82-S-50.

Test area: 1/4 hectare divided into four equal plots.

Test conditions: Same as early-seeded sorghum tests (with a seeding period between 15 May and 15 June) except 1) the choice of the test site and 2) no fertilizer was applied. Farmers were asked by the extension agent to conduct the test on a field that had been cultivated in cotton in 1984 but had been cropped in sorghum in 1983 that had been heavily infested with *Striga*. Note that these test conditions were specifically chosen to compare S35 to local varieties under adverse conditions of early seeding, no fertilizer and *Striga* infested fields. 82-S-50 is included due to its reported tolerance/resistance to *Striga* in Burkina Faso.

Tests statistics and linear correlations with grain yield

Variable	*Mean*	*Stand.dev.*	*r*	*Prob.*
Date of seeding	13/6	9 days	NS	
Density pl/ha	40247	1163	.42	.000
Days to reseeding	10.3	9.9	NS	
Days to weeding	22.5	12	NS	
Rainfall 1-90 d.a.s.	503	117	−.423	.000
Soil pH (30cm)	5.87	.76	NS	
% sand (>.5mm)	26.1	9.3	NS	

Analyses of variance

Grain yield
Variety S35 – 1605 kg/ha
Variety Local – 1516 kg/ha
Variety S34 – 1380 kg/ha CV = 25%
Variety 82-S-50 – 1556 kg/ha

No significant difference in yield.

Plant density
Variety S35 – 42764 pl/ha
Variety Local – 42477 pl/ha
Variety S34 – 41238 pl/ha CV = 19%
Variety 82-S-50 – 34509 pl/ha

The densities of the first three varieties are all significantly superior to that of 82-S-50.

Observations and Conclusions

1) Farmers report that 83% of the plots in this test were infested with *Striga*. This compares to an average of 50% of plots infested with *Striga* across tests *not* purposely chosen for *Striga* infestation. Due to lack of field techniques for measuring the degree of *Striga* infestation that are highly correlated to yield, it is impossible to evaluate varieties for relative tolerance or susceptibility to *Striga* other than the overall mean yields. The mean yields indicate that S35 and the local varieties are not different in *Striga* infested fields than in non-*Striga* infested fields. At the outset of the season it was believed that *Striga* infestation would be more severe on early seeded than late-seeded sorghum thus the choice of early seeding for this test. However, from field observation it seems that the early seeded tests escaped more of the brutal effects of parasitism by *Striga*. The mean yield of plots infested with *Striga* was 1391 kg/ha by comparison to 1939 kg/ha for those not reported infested with *Striga*.

2) The mean densities were low as in the early seeded test and there was a high correlation between yield and plant density. The yield of 82-S-50 was surprisingly high given the low mean density of this variety.

Comparison of S35 and Local Varieties Across Two Years and 165 Sites

This synthesis is an attempt to assemble and analyse on-farm test results on S35 in Northern Cameroon for 1984 and 1985. The results are based on 87 on-farm sorghum varietal tests conducted in 1984 and 78 varietal tests conducted in 1985 that included S35 and a local variety. It is presented in the spirit of providing elements of an extension package that can be modified by experience of future years; from station research, from on-farm tests, and most important, from feedback from extension. Together, the observations in 165 farmers fields during two years of a new sorghum variety provides a body of knowledge that is awesomely powerful and exciting. Undoubtedly this mass of information has only been scratched and by our humble attempts at analysis and interpretation.

Comparison of Means by Paired t-tests

For 87 sites in 1984

Variety S35	– 1336 kg/ha	CV = 66%
Local varieties	– 762 kg/ha	t = 7.84**
Difference	– 574 kg/ha	HS (prob. = .000).

For 78 sites in 1985

Variety S35	– 1693 kg/ha	CV = 37%
Local varieties	– 1540 kg/ha	(t = 2.28*
Difference	– 153 kg/ha	S (prob. = .024)

For both years across 165 sites

Variety S35	– 1505 kg/ha	CV = 52%
Local varieties	– 1130 kg/ha	t = 7.14**
Difference	– 375 kg/ha	HS (prob. = .000)

Discussion

From the above analyses it would appear that S35 is unequivocally superior to the mean of local varieties. There is however considerable differences in means for the two different years. Note that the mean yield of the local varieties increased by 102% from 1984 to 1985 while S35 increased only 27%. The improved yields of the local varieties in 1985 can be attributed to higher and better distributed rainfall, a strong response to earlier dates of seeding in 1985, and higher plant densities in 1985. The success of S35 in 1984 can be attributed to its short growing cycle which permitted reasonable yields despite low and erratic rainfall and relatively late dates of seeding. Multivariate analyses can be used to demonstrate the above conclusions with the notable exception of the effect of rainfall across sites within a year and across years. It has been impossible to find a suitable indicator for rainfall that accounts for a significant amount of sorghum yield variability.

Analysis of Variance with Years and Regions

The above paired t-tests may give an illusion of clear superiority of S35 over local varieties within and across years. However, in a paired t-test comparison, the variability across sites and years is excluded. Due to the enormous difference in yields between the two years an analysis of variance was undertaken by the following model:

$$\mathrm{YLD}_{ijkl} = \mathrm{Y}_i + \mathrm{R}j + \mathrm{YR}_{ij} + \mathrm{L}_{(ij)k} + \mathrm{V}_l + \mathrm{VY}_{il} + \mathrm{VR}_{lj} + \mathrm{VRY}_{lij} + \mathrm{E}_{(ij)kl}$$

where Y = year; i = 1, 2. (random)
R = region; j = 1, 2, . . . 5. (fixed)
L = location; k = 1, 2, 3, . . . 11. (random)
V = variety; l = 1, 2. (fixed)

Data from one entire region and some data from other regions was omitted to obtain a data set that was complete and balanced for analyses by the STATISTIX program. Eleven sites per region per year (or 88 sites) were arbitrarily chosen from each of the four regions. This pruning of sites resulted in the following means which are approximately 50 kg/ha higher for each variety.

S35 = 1551 kg/ha
Locals = 1197 kg/ha

Anova table

Source	*DF*	*SS*	*MS*	*F*	
Year	1	17396000	17396000	83.17**	HS
Region	3	12520000	4173400	6.58	NS
Varieties	1	5513600	5513600	2.20	NS
Y × reg	3	1903900	634640	.75	NS
Y × var	1	2505000	2505000	11.98**	HS
Reg × var	3	1140300	380090	.69	NS
Loc/y × reg	80	67892000	848650	4.06**	HS
Y × reg × var	3	1657100	552360	2.64	NS
Loc × var/y × reg	80	16733000	209160		
Total	175	127260000			

Note that in the above model, VARIETIES are tested by the MSE for Y × VAR interaction and the resultant F statistic is far from being significant. This is not too surprising as most of the variability in the model is accounted for by the effect of years and its interactions. The conclusion from the above analysis is that the superior variety depends upon the year and data from more years are needed to ascertain if S35 is really superior to the local varieties.

Regression of S35 Yield on the Local Variety Yield Across Sites

In order to compare the relative performance of the varieties in different environments the grain yield of S35 was regressed on the grain yield of the local variety at each site for the three different groups of data comparing S35 and the local varieties.

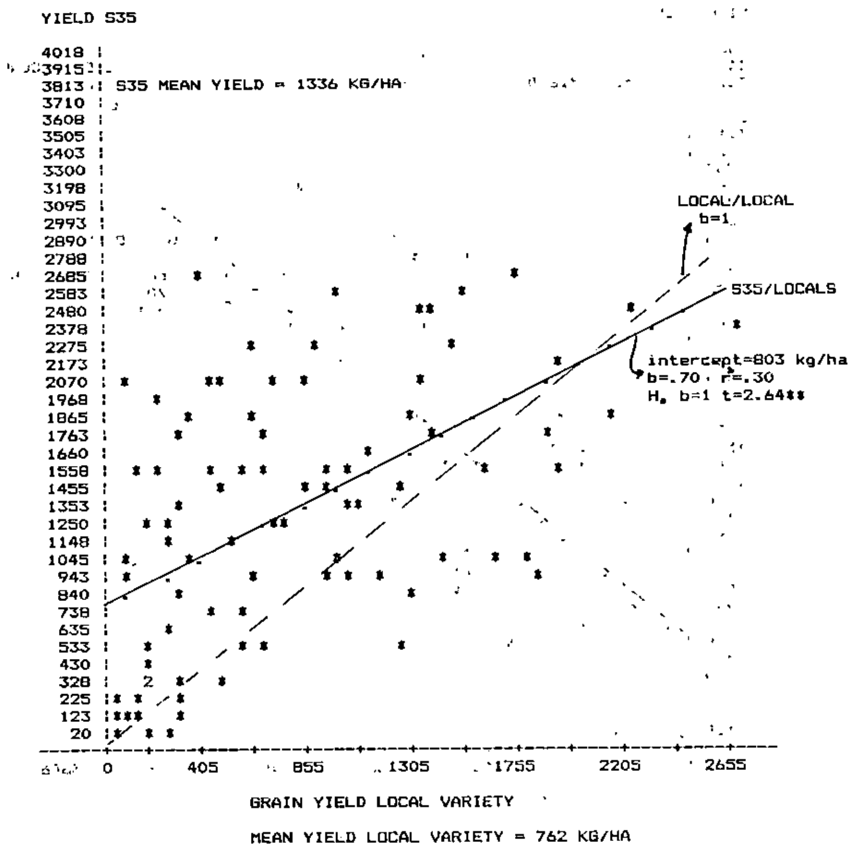


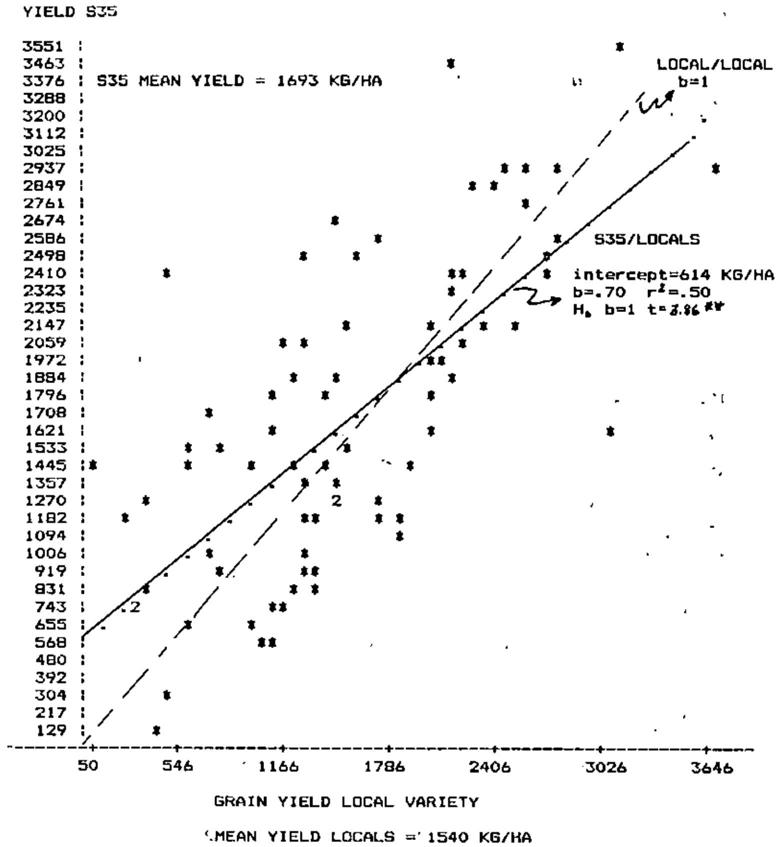
Figure 2 Grain yield of S35 regressed on grain yield of the local variety at each of 87 sites in 1984

Discussion of Regressions

Due to the significant effect of years and the year by variety interaction in the analysis of variance, it is surprising how the relationship between S35 and the local variety remains similar across the two very different years. Note that the slope of the S35/local regression line is almost the same in all three comparisons. This stable relationship between the two varieties suggests the contrary of the preceding analysis of variance in as much as either year can be used to establish the environments that favor S35 thus data from more years is not necessary. The slope of the S35/local regression line when tested against the theoretical line of local/local, or b=1, is significantly different for all of the comparisons.

In 1984 the points are clustered into relatively low-yielding environments. The distribution of points is quite different in 1985 but the relationship between the two varieties remains the same. The difference between the two years can be seen as a significant shift in environments, not in variety response to the environment.

S35 is consistently yielding more than the local variety in low yielding environments. This might surprise the advocates of that school of sorghum



*Note**
Legend at bottom of illustration

Figure 3 Grain yield of S35 regressed on grain yield of the local variety at each of 78 sites in 1985

improvement thought who believe that local varieties, being selected over time, are better adapted to low-yielding environments. Or inversely, that improved varieties require high yielding environments to express superiority over local varieties.

Finally, the consistent variety by environment interaction indicated by the crossing lines for all 3 of the regressions, indicates a potential for genetic improvement in low-yielding environments that might be extended to all environments. In as much as rainfall shortages or drought periods contribute to low-yielding environments in the semi-arid tropics, it seems possible for plant breeders to exploit this potential and provide farmers with higher yielding varieties than the local varieties in low-yielding environments.

Optimum Date of Seeding for the Sorghum Variety S35

For this study all of the above S35 sites were used as well as thirty-eight sites where S35 was used in on-farm soil preparation tests. From this total of 203

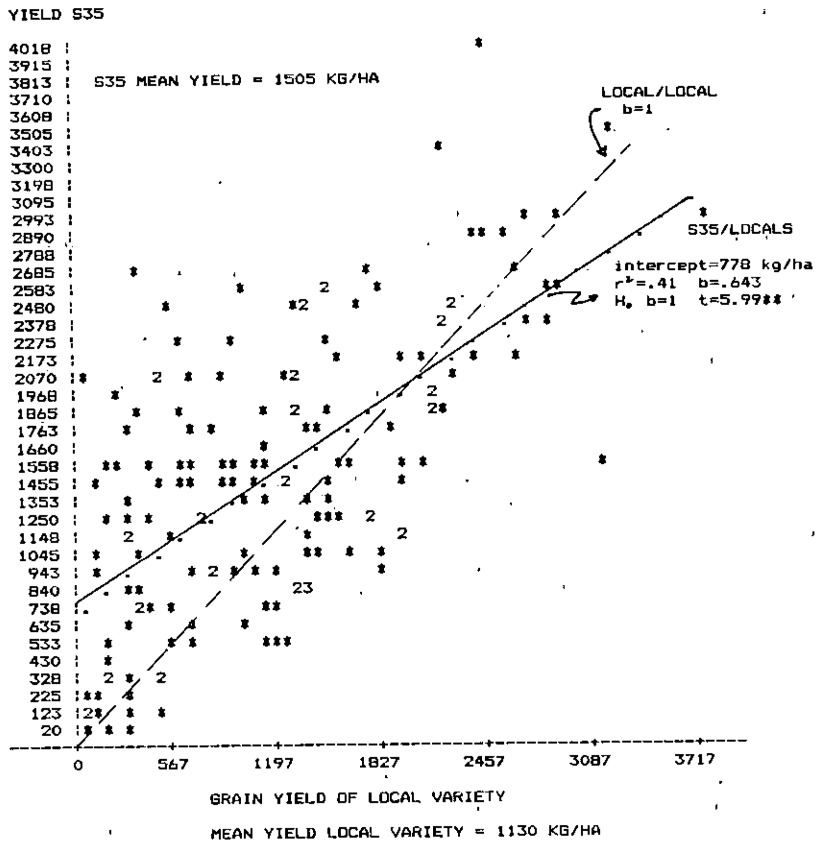


Figure 4 Grain yield of S35 regressed on the local variety at each of 165 sites in 1984 and 1985

sites, those sites seeded before the 10th of June or after the 20th of July were eliminated.

From simple linear correlation a negative slope of 16 kg/ha per day is obtained indicating that S35 should be seeded as early as possible. However, despite the statistical significance of this correlation, prob. = .007, it is unsatisfactory because the coefficient of correlation is low, r = .224, thus accounting for less than 5% of total yield variability with date of seeding.

The quadratic equation with date of seeding and date of seeding squared gives more satisfaction. This equation indicates the optimal date of seeding to be between the 19th and the 20th of June for an estimated yield of 1697 kg/ha. The statistical significance, prob. = .003, improves with this model though date of seeding still only accounts for about 5% of total yield variability. A comparison of the linear and quadratic effects of date of seeding on yield is given in the following graph.

None of the following factors; plant density, year, rainfall, or region were in significant interaction with the optimum date of seeding. Nevertheless, the crude field test used to classify each farm site soil as either predominantly sandy-textured or predominantly clay-textured gave valuable insight into the optimum date of seeding of S35. In general, in sandy soils the optimum date becomes earlier, 5th of June, and in clay soils the date becomes later, 26th of June.

Number of Days from Seeding to Reseeding

During the two years, field observations have indicated an effect of delayed reseeding on yield of S35 and this short study attempts to quantify this loss. There is a general tendency among farmers to wait up to three or four weeks after seeding to reseed. Often seeding in less than optimal soil moisture conditions that characterize the beginning of the season, the farmer is hoping for more rain or less rain to see if the last viable seed will emerge before undertaking reseeding. By that time the first seeding is well developed and the farmer opts for transplanting at the time of first weeding instead of reseeding to improve plant stands. Of the 203 S35 tests during the two years, 69% of them were reseeded.

The linear correlation between grain yield and number of days from seeding to reseeding is highly significant (prob. = .01) and indicates a loss of yield of 25 kg/ha per day of delay in reseeding that accounts for 5% of the variability of yield of S35. Soil texture also influences the loss due to delay in reseeding such that the loss is more important in sandy soils than in clay soils.

Study of the Optimal Plant Density for S35

This study undertook to combine research station data from the sorghum breeder with the on-farm test data for the same two years to determine the optimum plant density for S35 due to the absence of high plant densities in the on-farm data and the predominance of high densities in the research station data. It included the following number of plots and their mean plant densities. The plant densities are based on actual plant counts made in the field approximately 30 to 40 days after seeding.

Research station plots in 1984 and 1985	= 83 plots with 61,882 pl/ha
Onfarm tests in 1984	= 87 plots with 51,100 pl/ha
On-farm tests in 1985	= 167 plots with 43,846 pl/ha
Total	= 286 plots with 51,361 pl/ha

The best fit between plant density and grain yield for this mass of data was a simple linear correlation, that explains 19% of the variability of yields, is highly significant (prob. = .000) and implies a gain in grain yield of 55 kg/ha for an increase in plant density of 1000 plants/ha.

Applied strictly to the station data the linear correlation, still the best fit of the data, implies an increase in yield of 65 kg/ha for every 1000 plants/ha but only accounts for 11% of the variability in grain yield.

The problem is with the on-farm test data. The linear correlation is not significant and accounts for less than 1% of the yield variability. This lack of linear correlation is predominated by the different relationship between plant density and yield in the two different years. Remember that S35 grain yields increased in 1985 despite an important decrease of about 10,000 plants/ha in plant density. Up to 25% of the grain yield of S35 in 1984 can be explained by the highly significant relationship of plant density and its interactions with the date of seeding and the number of days to reseeding: (DEN=DENSITY, DOS=DATE OF SEEDING, RES=DAYS TO RESEEDING)

YIELD of S35 = 422 + .115(DEN) − .0005(DOS) (DEN − .0007(DEN) (RES)

No significant relation could be found between plant density and yield for the 1985 on-farm test data. However panicle density is the single variable most highly correlated to yield of S35 in 1985. The following model accounts for 20.53% of total S35 variability in 1985 and is highly significant (PROB. = .0000):

$$\text{YIELD of S35} = 735.5 + .09722(\text{DEN}) - .00000086001(\text{DEN})^2$$

This model predicts the optimum panicle density at 56,523 panicles per hectare and an expected yield of S35 at 2012 kg/ha. Note that the yield of the local variety across sites in 1985 was even more sensitive to panicle density. The simple linear correlation accounts for 33% of total variability and is highly significant and indicates an increase in yield of 319 kg/ha for every increase of 10,000 panicles per hectare.

In resume plant density can have an important impact on yield. The interaction of year with density indicates the need for more years of on-farm data to recommend a different planting density. However, the station and on-farm data indicate that higher densities need to be tested.

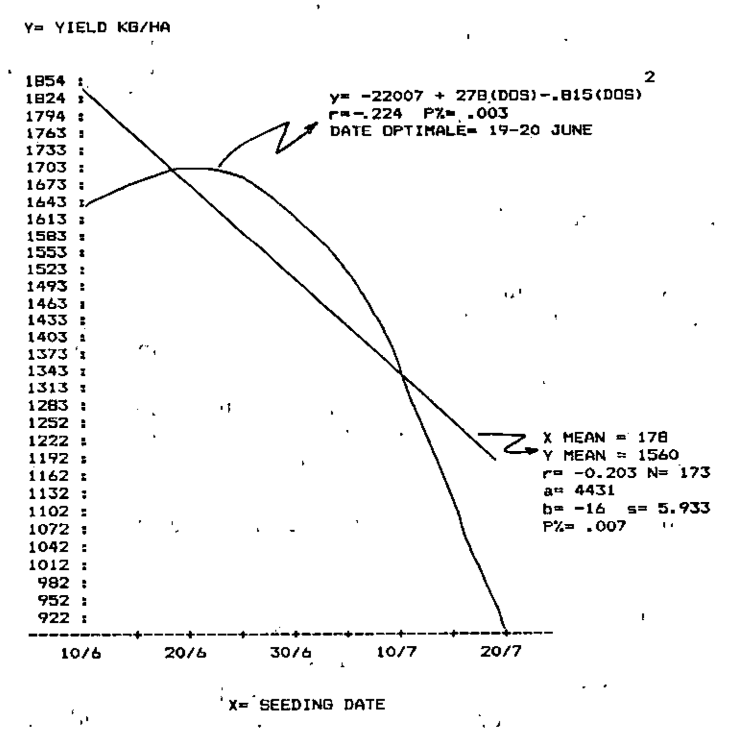


Figure 5 Optimum date of seeding (DOS) of sorghum S35 from 1984 and 1985 on-farm test data for the period between 11 June and 20 July.

A Summary of Characteristics of Sorghum Variety S35

History

Origin: India
Parents: M91019-6-1-16-4 (Selection)

Introduction into Cameroon

Dr. O.P. Dangi, Sorghum Breeder, NCRE Project/IRA/IITA/USAID, introduced promising breeding materials from Dr. N.G.P. Rao, Sorghum Breeder, ICRISAT/IAR/ABU, Zaria, Nigeria, during the 1982 rainy season, who jointly evaluated material at the Guiring Research Station that year. In the subsequent years Dr. Dangi continued selection and evaluation.

Years Tested in North Cameroon on Research Stations

1982: A preliminary sorghum varietal yield trial at Guiring Research Station during 1982 rainy season followed by selection program during off-season of 1982-1983.
1983: Ten locations of IRA stations, sub-stations and parastatal bodies under multilocation variety yield trial.
1984: Seven locations of IRA stations, sub-stations and parastatal bodies under multilocation variety yield trial.
1985: Seven locations of IRA stations, sub-stations and parastatal bodies under multilocation variety yield trials. This trial was conducted in the rainfall zone having less than 800mm rainfall in the different ecological zones of North Cameroon.

Description/Characteristics

- Non-photosensitive
- 90 day variety from seeding to harvest in Northern Cameroon.
- Average weight of 1000 grains = 23.8 grams (111 on-farm sites in 1985).
- Average weight of one liter = .77 kg (111 sites in 1985).
- Average grams grain per panicle = 41 grams (1985 on-farm tests).
- *Striga* susceptibility – no significant difference from the local varieties.
- Stem Borr susceptibility – no data on loss of yield due to stem borer.
- Grain mold susceptibility – susceptible but not serious attacks in 1984 and 1985 on-farm tests.
- Lodging – some stem lodging observed in on-farm tests in 1985.

Recommendations

1) Manure application – 5 tons/ha before soil preparation.
2) Soil Preparation – no data to show that plowing is necessary.
3) Date of seeding for the Extreme North – 16th to 20th June.
4) Reseeding – 5 to 7 days after seeding.
5) Planting density – 62,500 plants/ha (80cm × 40cm × 2 plants/hill).
6) Fertilizer – 100 kg/ha urea incorporated 30 days after seeding.

Other Results from On-farm Testing Concerning S35

Soil Texture No significant difference in yield between sandy and clay soil across 203 sites in two years.

Percent Large Sand No correlation between grain yield of S35 and % sand in top 30cm based on 113 sites in 1985 with an average of 28.3% sand >0.5mm.

Soil pH (30cm depth) No correlation with yield based on 113 sites in 1985 with an average of pH of 5.84.

Seeding to Harvest Total Rainfall

1984 – positive but no significant correlation with yield based on 86 sites with average rainfall of 376m.

1985 – negative and highly significant correlation with yield (prob. = .009 and r = 0.243) based on 113 sites with an average rainfall of 540mm.

Collaborating Farmers Comments on S35

Almost all farmers will plant significant amounts of their land to S35 next year due to the high yields and earliness of S35. The grain quality of S35 for local preparation is also appreciated. Some farmers complain of loss due to birds in 1984 and 1985 and some farmers in 1985 observed stem lodging in S35.

In addtion, the extention agency SODECOTON is undertaking a pilot extension of S35 in 1986 that will encompass approximately 2500 hectares of this variety.

Acknowledgements

To the 244 local farmers who volunteered to conduct on-farm tests in 1985 for all of their hard work in the field and for their cooperativeness in discussion.

To the more than 300 SODECOTON field agents who participated in the supervision of on-farm tests in 1985 for all of the evening, weekend, and vacation time willingly spent receiving and satisfying SAFGRAD team visits.

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SYMPOSIUM DISCUSSIONS AND RECOMMENDATIONS

PLENARY SESSION

Summary of Discussion

The need for an integrated study of past and present issues on agricultural development in Africa as the foundation for developing a food security research agenda was emphasized. It was also pointed out that the food policy/security concepts like "Food First", "Food Self-sufficiency", "Food Self-reliance", "Food Security", should be clearly defined before undertaking any research on the food problem in Africa.

A few of the causes of Africa's agrarian crises of 1970–85 were highlighted. The main thrust was on the need for national and sub-regional food security studies, allocation of public expenditure on agriculture to develop prime movers of agricultural development (human capital, research, infrastructure, etc.), strengthening of the institutional base, research in export crop performance, keeping pricing policy of food crops in perspective in relation to technology generation, human capital improvement and strengthening agricultural institutions to achieve multiple objectives.

Three basic challenges facing food and agriculture in Africa from 1986 to the year 2000 were discussed. These include the food production-population race, the poverty-hunger and food security battle, and the rural employment imperative. It was emphasized that background issues, namely, food security concepts, project or policy level of analysis, and political sensitivity should be examined and debated before food security research priorities are spelt out at the household, village, national or regional levels. Finally, research priorities were discussed under the following main areas: Efficiency in agricultural production, Marketing, Food consumption and nutrition, Managing foreign exchange, Grain reserves and food aid; International trade and national and sub-regional policy options.

During the discussion, questions raised included the role of social scientists in food security research, the kinds of research priorities to be considered where food marketing is not well developed, priority to research in high potential areas vis-a-vis in resource poor areas, food crops vis-a-vis cash crops research, irrigation potential in semi-arid areas, study on the movement from farming systems research to resource management; relative and overlapping concepts of food security; kinds of food strategies, food security policy on the basis of *comparative advantages* and the farm level micro linkages in food security research.

It was commented that the role of social scientists was to collect general information, conduct consumption surveys, study the marketing margins, grain storage, cost aspects of food availability, etc. The main area in food marketing research is marketing margins of commodities. It was mentioned that high research priority should be given to high potential areas rather than poor natural resource regions. The question of food crop vis-a-vis cash crop research should be resolved on the basis of national prorities. It was emphasized that food security policy should look at international trade opportunities and work on the principle of comparative advantage.

Other issues such as food production on the basis of comparative advantage, emphasis on food production oriented strategy rather than distribution and marketing strategies, attracted much of the participants' attention during the discussion. It was stressed that food self-sufficiency should have high priority in national development plans in African countries especially due to high uncertainty and risks experienced in international political relationships. This point is well presented in the *Lagos Plan of Action* of the Organization of African Unity.

In addition to intensification of production in high potential areas, efforts should be continued to develop arid and semi-arid areas to increase food production to feed the growing populations in the affected countries.

It was also pointed out that food marketing systems are not well developed in most of the African countries. Food strategies should therefore emphasize the distributional aspect of food security in these countries.

Strategies for strengthening regional research cooperation were discussed, while important considerations for promoting research networks were outlined. Regarding crop productivity under drought stress, lack of adequate production of biomass in the sudan savanna and sahelian zones tends to limit the use of mulching as a water conservation alternative. It was stressed that research should provide the technological possibilities for conserving water in order to influence farmers to shift their current strategy to intensify their agricultural activities by integrating crop and animal production systems. With regard to sustaining the generation of technology at regional level, the flow of technology has been shown to be both multi-directional and reciprocal.

Livestock losses due to drought was identified as a critical constraint to crop production. For example, water shortage for animals, limits the use of animal power. It was emphasized that making large amounts of hay during good rainfall years to sustain animals could be an effective policy alternative if labour resources were not scarce for farmers. Although animal production could complement crop production both in interrelated resource cycling and economic activity providing milk, meat, animal manure, power, etc., great care must be taken regarding the negative aspect of over-grazing which increases soil run off and induces desertification and drought. As regards optimum levels and stocking rates, more monitoring research is necessary since destocking is an unaccepted strategy by government and livestock owners. Viable options for pastoralists should be made available if stocking limits are to be improved. Research carried out in Northern Nigeria, Mali, Botswana, etc., indicate difficulty of changes – since range land producers have short-term objectives. The problem of how to get an animal which has suffered from drought to recover and produce again was raised. In order to reduce overgrazing, it is necessary to consider technological options such as minimum tillage systems requiring less power. Conducive government policies such as reducing or alleviating taxes during drought years, could facilitate recovery and post-drought rehabilitation of livestock.

There seemed to be a general consensus by participants on the development of stable, higher yielding and drought resistant crop varieties as the avenue of greatest promise for drought conditions in Africa. The paradox, however, is that while breeding for drought resistance is an urgent issue, this novel research activity is expensive since it requires much knowledge, equipment and infrastructural facilities. Plant breeders, agronomists, etc., in different national research programmes, need to be supported to improve their research capabilities. In this regard the following roles have been identified for regional programmes:

(a) To promote research cooperation for screening of breeding materials among NARS which are working on similar objectives. Sharing of facilities common to several neighbouring countries – suitable screening sites should be supported by regional programmes to solve specific problems; the major effort being to breed for drought tolerance. Any good material that can be identified could be distributed to all cooperating countries.

(b) To facilitate the flow of germplasm and technical information. In order to minimize duplication of efforts, research should not be limited to yield trials but should also include several advanced lines to be evaluated within the national crop improvement programmes. Activities of IARCs should concentrate on germplasm distribution, accumulation and distribution of information on new elite sources, such as materials resistant to diseases, droughts, insects, etc. Selected regional nurseries for specific purposes like disease evaluation, etc., should be established on a regional basis.

(c) To facilitate the realization of these objectives, multi-disciplinary research teams consisting of highly qualified scientists from different national research programmes, should be linked.

(d) To promote short- and long-term training at B.Sc.; M.Sc. and Ph.D. degree levels. This area is absolutely essential in upgrading the staff levels of many of the NARS for long-term improvement of research capabilities in solving food grain production problems.

(e) To promote the improvement of experiment station management through specialized workshops and training for research administrators.

After considering the weaknesses of current national research programmes, the following research gaps have been identified:

- Lack of proper characterization of the environment and clear definition of the nature of drought problems in each major growing area, including identification of relevant traits for various environments and prioritizing such traits to restructure research strategies;
- Lack of adequate facilities for direct screening and acceleration of breeding material. Effective regional cooperation is necessary among SAFGRAD member countries, particularly to utilize good sites to screen drought tolerant lines;
- The absence of research geared towards increasing the cropping period in relation to fallow land as well as research in alternate cropping systems and intercropping to minimize risk of crop failure;
- Need for more research on soil types in relation to availability of water and crop establishment problems. Orientation of agronomic research should be more problem-solving, considering different farm conditions.
- Lack of resource base for quality research (inadequate qualified researchers, funding, and poor working conditions in many national research programmes).

RECOMMENDATIONS

Policy issues

(1) The development of national food security systems (food banks) should be encouraged, and food security should have high priority in national development plans of African countries, which tend to suffer from high uncertainties and risks experienced by environmental stress and in international political relationships.

(2) It is noted that less than ten percent of government resources are allocated to the development of agriculture in most SAFGRAD

countries. It was recommended that SAFGRAD, through the OAU/STRC mechanism, should play a catalytic role in sensitizing African governments to allocate more resources to agricultural research and development.

(3) It is recommended that greater emphasis should be placed on land use control and management practices. Increased research support is needed in soil-water conservation, integration of multi-purpose trees, food crops and livestock. There should be intensified crop research and production in areas of most stable and consistent rainfall, leaving sahelian and other low rainfall zones to cattle grazing.

(4) It is recommended that an agency should be encouraged and provided with the necessary support to coordinate environmental stress analysis in sub-Saharan Africa. This would provide a regional agroclimatic data base that would be accessible to all NARS.

GROUP I. CROP PRODUCTION

Summary of Discussion

To increase drought tolerance in food grain crops in semi-arid tropics, it is important to evaluate materials at representative sites. It may be necessary, therefore, to support and develop the facilities of sites in selected NARS. Identified sites would serve for evaluating and screening materials that could be available to all participating countries.

Breeding and improvement of food grain crops should be concentrated at locations where the soil, climate and physiography have been adequately studied. In general, climatic quantification should include the frequency, duration and intensity of drought periods in relation to development of plants, in terms of hydrological balance. Adequate long-term data base needs to be assembled. A central data repository unit is necessary to provide services to different NARS.

It was suggested that local sources of germplasm such as the Guinea sorghums are well adapted to semi-arid regions. Phenotypic alteration of these types of sorghum could be exploited even though these groups of sorghum are very difficult to improve or modify through breeding. Major phenotypic alteration can also be attained by using exotic varieties that possibly carry some Guinea traits. Improvement of the indigenous research capabilities of selected national programmes could enable breeders to develop and evaluate their own hybrids. It was reported that, in general, hybrids, compared to varieties, proportionately perform better in stress, compared to non-stress situations.

Several comments were made at the symposium about hybrid seed availability for the small farmer. It was pointed out that a local seed industry could evolve once suitable hybrids are developed. For example, Hageen Dura No. 1, a hybrid developed in Sudan, currently being multiplied on a large scale by local seed companies. As to cropping systems, concern was expressed about pushing maize into marginal growing conditions, the semi-arid drought prone areas. In Southern Africa, in the traditional drier areas, farmers intercrop maize hybrids and sorghum varieties in order to minimize risks of crop failure. Considering similar practices elsewhere, particularly in drought-prone regions, there is need to establish intercropping systems of combining compatible varieties and hybrids of sorghum and maize or millet.

Cooperative regional sorghum improvement in Eastern Africa has been facilitated by SAFGRAD/ICRISAT programme through regional trials and nurseries, introduction of germplasm, organization of workshops and advice to the national programmes of the region. This region was defined to include eight countries – Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania and Uganda. Thirty-two released and promising varieties were identified (5 varieties for high elevation above 1,800m, 8 varieties for intermediate elevation, 1,500–1,800m and 19 varieties for low elevation below 1,500m).

It was pointed out that more emphasis had been placed on the utilization of conventional and traditional breeding methods. However, substantial amounts of hybridization activities are currently being carried out in the region: in Ethiopia, Sudan, Uganda and Tanzania. Although the advantages of hybrid sorghum had been demonstrated in these countries, it is only the Sudan that had moved hybrid sorghum from research station to large-scale seed and grain production. The percentages of grain yield increase of hybrids over varieties was reported to be higher under stress, indicating the superiority of hybrids in yield and stability across environments.

Discussion during the symposium showed that there was apparent tendency for national research programmes to develop their own hybridization programmes. It was pointed out that hybrids were only useful if growing conditions are good and require higher inputs such as fertilizer. Although the full yield potential of hybrids may need high inputs, the differences in yield between variety and hybrids become greater as growing conditions become harsher. The spin-off advantage of hybrids is that it would pave the way for a local seed industry to evolve. It was stressed that it was not productive to argue the variety vs hybrids issue in the abstract, but to develop good adapted hybrids and varieties and determine their value in a range of climatic conditions.

Recommendations

Improvement of crop production under drought conditions without the modification of the environment is one of the most difficult tasks in scientific research. Solutions should come from multidisciplinary approaches to the problems of crop improvement.

Three major components involved are:

- Research for crop improvement.
- Conditions and facilities to undertake research.
- Education and training to strengthen appropriate manpower needs.

(1) It is recommended that existing knowledge should be used to identify research and management priorities focusing on issues relevant to specific drought prone situations. This symposium revealed that a significant amount of new knowledge has been generated in recent years and this knowledge can be used to improve crop production research in dry regions. Such research should continuously be done and supported.

(2) It is recognised that, although a certain amount of crop production technology has been developed, much more is required, considering the complexity and severity of the problems of production under drought stress. There is need to strengthen and develop national programme research capabilities to tackle this important area. This should be done by various means, such as:

(a) strengthening collaborative research among national programmes, regional and international agencies.

(b) Identification of research areas that can be described as attracting donor support. Such areas include –
- plant breeding for dry areas.
- Basic research in the physiology of crops in dry areas.
- Research in the development of breeding methods for crops grown in dry areas.
- Capitalisation on an expansion of germplasm resources.
- Identification of the most appropriate locations to undertake research on drought resistance.
- Improvement of communications between scientists.
- Recognition of the importance of research in the area of post-harvest technology to minimize substantial crop losses.

In view of these tasks, expertise is needed in identifying needed facilities, the working environment and experiment station management in order to achieve quality research results. It is recommended that these needs should be quantified for donor support.

(3) The individual scientist has a key role to play to achieve these objectives. It is recommended that scientists be supported by:
(a) Identifying the appropriate manpower needed.
(b) Providing support through education and training.
(c) Providing encouragement by adequate personal compensation based on creativity.
(d) Improving living and research conditions.
(e) Providing adequate opportunities for interaction with other scientists.

The transfer of new technology to the farmer, depends on supportive government policies including market opportunities.

In order to strengthen cooperation among countries, a policy should be developed to facilitate movement of scientists, germplasm and breeding stocks throughout the African continent.

GROUP II. SOIL-WATER MANAGEMENT

Summary of Discussion

The African continent, although endowed with immense natural resources, has faced serious food crises since the last two decades. The continuous decline in per capita food production has been attributed variously to the drought, rapid population growth and degradation of the resource base for productive agriculture. Although these factors may have exacerbated the food crisis, the root of the problem lies in the neglect of the environment in general and improvement of soil fertility, conservation and water management in particular. Soil degradation has consequently become a major constraint to food production in semi-arid sub-Saharan Africa. Technology and methodology for improved soil fertility, conservation and water management are therefore urgently needed. In addition, development of an integrated production system which recycles resources and consequently conserves and optimizes available soil resources was suggested.

The drought that destabilized food grain production in many countries of Africa is not unique to the region. Although the droughts of the 1960s and 1970s of the Sahel received world-wide attention, more than 20 droughts have occurred since the 16th century in the same region. Previous patterns of climate seem to suggest that droughts occur in one or more regions of Africa every year. Two or more droughts affect large areas of the continent every decade while extremely protracted and widespread droughts occur about three times in a century, although the precise geographical area of incidence is not predictable. In general, the erratic pattern of rainfall distribution, as well as poor soil management techniques to conserve moisture, have also contributed to poor food grain production.

Initially, discussion centred around the need for rainfall record analysis in relation to crop production. With regard to utilizing long-term rainfall data, predicting the occurrence of "dry spell bands" within five- to ten-day intervals, during the growing season, was proposed since such information could help farmers to decide on crop production activities and maximize the use of available moisture. The importance of water use efficiency through manipulating tillage practices, crop and other cultural practices, particularly in the semi-arid regions, was emphasized. It was also pointed out that water and soil conservation techniques could not be universal and need to be modified according to soil type, amount and pattern of rainfall. It was stressed that the problem of soil fertility constitutes a significant impediment to increased food production. Restoring the soil fertility poses important challenges for research and policy on resource management. Insufficient quantities of nitrogen and phosphorus also limit the produciton of semi-arid food grains.

A research study on characterization of soil Phosphorus (P) status, crop P resources, P removal and balance in different cropping systems, residual P effects, efficient use and effectiveness of different P sources (with particular emphasis on local phosphatic rocks, role of mychorryza, genotype and P level interactions, drought stress and P level interactions) need to be emphasized.

Similarly, research investigations on the characterization of soil Nitrogen (N) status, crop N responses, N removal and balance in different cropping systems, residual N effects, efficient use and effectiveness of different N sources, role of leaching and volatilization losses on the N balance, genotype × N level interactions, drought stress × N level and timing of application interactions need to be studied.

Different parameters of soil fertility in relation to drought were discussed. Low inherent fertility of soils in semi-arid tropics is partially due to total removal of crop residues for its competing uses as fuel, construction, livestock feed, burning, etc. It was pointed out that certain soils particularly those common in the semi-arid tropics (such as alfisols) are low in organic matter in general, and nitrogen, phosphorus in particular. In addition to incorporation of organic residue and developing appropriate cropping systems, the need for integrating livestock for traction, fuel and food, was emphasized.

It has been noted that the major option to sustain food production particularly in densely populated regions of the semi-arid tropics is the intensification of agricultural production of which livestock manure and other organic residue application is known to improve the physical and physio-chemical effect of soils in addition to the provision of nutrients.

Recommendations

(1) Several tillage practices suitable to dryland agriculture are available and many of the techniques (ploughing, tied-ridges, etc.) have been

successfully tested. It is recommended that energy efficient and conservative tillage systems, which improve soil structure, reduce weed growth, labour and fertilizer inputs, should be studied at the village level with appropriately designed on-farm trials.

(2) Attention must be given to soil fertility research and management, more particularly in relation to:
- harmonization of methodologies for soil fertility evaluation;
- basic chemistry of soils and their reactions to the addition of various fertilizers;
- problems of minor element toxicity and soil salinity; and
- crop residue and manure management research; priority should also be given to the development of local fertilizer resources and more particularly, to rock phosphate.

(3) Water is the most important constraint to crop production in the semi-arid zones of Africa. Conservation and efficient use of water are consequently critical to the development of a rational agricultural resource management system. Management systems which minimize runoff and erosion, and maximize water infiltration into the soil profile, should be given high priority. Research aimed at increasing the efficiency of rainwater utilization needs to be continued as well as that on the hydrology of surface and ground water. Rainfall pattern of several years should be examined carefully in semi-arid regions of Africa in relation to crop production.

(4) There is a need to intensify research on rural landscape management (anti-erosive control, water conservation) by considering traditional techniques and integrating agroforestry methods. Several ways and means have been suggested to minimize the evapotranspiration losses such as the removal of ineffective tillers, use of mulch, tillage practices, etc.

(5) Regional cooperative research could help to optimize human and natural resource utilization by linking more closely national, regional and international agricultural research and training institutions. Intellectual interchange among resource management researchers in their respective fields stimulates new ideas and creative solutions to difficult and complex problems and avoids pitfalls. Networking can enhance professional development by facilitating contacts among junior scientists and senior professionals. It can also promote a continuous flow of technical information and enhance the dissemination and adoption of research results. The management of soil and water in relation to food grain production would be the thrust of the suggested network activities.

It is recommended that SAFGRAD should facilitate the realization of such networks in order to enhance the application of soil and water management techniques among participating member countries.

GROUP III. FARMING SYSTEMS RESEARCH

Summary of Discussions

Fourteen papers on different aspects of farming systems research, FSR, were presented during the third and fourth days of the symposium. All except one of the papers dealt with different national approaches to farming systems research or aspects of FSR at the national level, and how FSR might be an appropriate research strategy to tackle the agricultural research problems associated with drier or drought-prone areas.

Participants generally agreed that the farming systems research approach was relevant and effective in drought-prone areas. It was suggested that in these high risk areas, fragile environments composed largely of subsistence agriculture, were very important to take note of the farmer's requirements and goals. Thus, it is important to emphasize the human elements, as occurs in the diagnostic and adaptive phases of FSR. Some of the lessons and results from FSR in the higher rainfall potential areas may be relevant in the drier areas. Participants felt that FSR in the drought-prone areas need to address the issue of management of the hazards associated with drought. There is a need to improve the farmer's options or numbers of options, while not leaving him open to higher risks. Management of risk in these areas is an important research topic.

Considerable discussion centred around how much emphasis should be given to FSR and commodity research. This issue was relevant because of the limited availability of funds, the general long-term nature of FSR, and the amount of manpower needed for it. Currently in East and Southern Africa, it was estimated that only 5% of the research manpower was involved in FSR. It was felt that 15 to 20% was probably a better partitioning (particularly if this meant 15 to 20% of each researcher's portfolio). Some participants suggested that separate FSR programmes could not only tax for more resources, but could also surface competition with other departments and this could impede the development of appropriate FSR. Rather, FSR could involve conventional researchers themselves, leading to integrated research and production systems in due course.

It appears that the requirements to undertake FSR may have been underestimated. The establishment of an FSR approach from scratch may mean the training of personnel at Masters and Doctoral degree levels. With the long learning curve of the FSR approach, it may take some countries up to 10 years to arrive at the stage of implementing such an approach.

Participants stressed that choosing the balance between the emphasis to be placed on diagnostic and adaptive research compared to commodity research, was something that could not be generalised for the drought prone regions. Some countries have a history of commodity research, the results of which have not been adopted by the farmer. In such countries, on-farm surveys and adaptive research are priorities. In other countries, the extent of commodity research is limited, and will need to be given priority, to generate technologies in response to farmers' needs and constraints.

Furthermore, it was stressed that livestock production is an important option and part of farming systems in drought-prone areas. It has high potentials for improving the productivity and the resource base of farming systems in these areas. Unfortunately, farming systems research effort has been mostly on cropping. There is a need to equally emphasize both cropping and livestock production systems in order to ensure complementarity of resource cycling to sustain food production in the drought-prone areas.

It has also been recognized that intercropping systems, as practised by farmers, may be an efficient way of improving production and of better exploiting time, rainfall and other resources. Intercropping systems have a very important role to play in better management strategies for higher and more stable agricultural production in the drought-prone areas.

Finally, on the basis of experiences from semi-arid areas of many countries, the need to develop technologies which are sustainable under low resource management by farmers was stressed. A special accent, however, needs to be placed on the development of proper soil-water management and soil fertility improvement techniques. Tied ridging has been demonstrated as a promising soil-water management technique in drought-prone areas.

Recommendations

(1) The farming systems approach to agricultural research is recommended for developing relevant and sustainable food production systems in drought-prone areas, particularly in view of the complex risk-avoidance strategies that may exist and the special need for preventing further environmental degradation.

(2) More emphasis should be placed on research to understand the farmer's approach to risk management in the drier areas and the adjustment mechanisms used when drought occurs. Such farmers' mechanisms and technical solutions should be used as a point of departure for developing technologies to cope with drought.

(3) As drought may result in a degradation of the environment and losses in the resource base, it is recommended that research efforts place emphasis on conservation of the resource base, particularly soil and water conservation. Research should emphasize the development of systems sustainable in the long term.

(4) The crop/livestock interface and agroforestry are important components of farming systems in drought-prone areas which can play an important role in preventing environmental degradation, improving soil-water retention and increasing crop productivity. These topics are of special relevance to drought-prone areas and may hold considerable potential benefits for such areas. Ways need to be sought to better exploit the potential linkages between crops, livestock and agroforestry.

(5) Greater attention should be paid to aspects other than that of production. These aspects include the farmer's socio-economic constraints, marketing, storage, etc. Although a lot of programmes claim to have an FSR approach to research, many do not address important issues such as the decision-making strategy of the farmers. Studying such issues will lead to a better understanding of why farmers do not adopt apparently "good" technologies. These studies will also pinpoint policy and institutional requirements needed for the adoption of some critical technologies.

(6) All agricultural researchers must see themselves as part of the farming systems approach to research, particularly where the clientele, the farmer, is the same. By adopting the farming systems approach to research on the problems of food production as part of each researcher's portfolio, the apparent conflict and competition between commodity researchers and the on-farm researchers will be reduced. One method of moving towards this goal would be to avoid separating "farming systems research" from the other disciplines, conferences and meetings, but rather to have multi-disciplinary sessions.

(7) There is need to improve capabilities for the transfer of appropriate FSR methodology and technologies in the drought-prone areas of sub-Saharan Africa. It is believed that a symposium such as this one on drought will continue to be a very important process in this transfer. FSR training, workshops such as those conducted by the University of

Zimbabwe, are recommended (for commodity researchers as well as FSR specialists) and should also be developed for the francophone areas of sub-Saharan Africa.

(8) FSR is, by nature, comprehensive, and this involves a long-term approach to the problems of realizing sustainable food production systems. With the harshness and variability of the environment of drought-prone areas in the semi-arid regions of sub-Saharan Africa, caution should be taken in the holding of expectations that envisage a "quick-fix", using FSR.

The production of food grains namely Maize, Sorghum, Millet, Cowpeas and Groundnuts in Semi-Arid Africa in sufficient quantities to meet the increasing demands of the rapidly increasing populations in this region continues to face many constraints including harsh and hostile climate, serious degradation of the fragile agricultural resource base and recurrent droughts. These problems are further compounded by poor infrastructures, inefficient marketing systems, weak national research policies and programmes, and extension services.

SAFGRAD, Semi-arid Food Grain Research and Development, a project funded mainly by the USAID and the OAU Scientific, Technical and Research Commission STRC, was established to co-ordinate agricultural Research and development efforts to substantially increase the production of food grains in 26 African countries in sub-saharan Africa. Certain key issues which are crucial for effective food grain production were examined at an International drought symposium held in Nairobi in May 1986. The proceedings of this symposium are presented in this book.

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